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FIBER OPTIC AND BROADBAND COAXIAL CABLE DATA NETWORK ALTERNATIVES FOR A FLYING MISSION BASE

By

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Air Force flying mission bases (strategic, tactical, and military airlift) require an upgraded and survivable data network to interconnect data processing equipment. The results of a comparative analysis of performance, survivability, and cost of fiber optic and coaxial cable data networks for this application are reported herein. The principal conclusion to be drawn from this work is that a fiber optic network offers survivability, reliability, and growth advantages at a cost comparable to an equivalent coaxial cable network.

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SECTION 1

INTRODUCTION

MITRE has completed a study under the sponsorship of ESD/XR to examine how the flying mission base data transmission requirements can be served by state-of-the-art networks. The networks to be considered use broadband coaxial cable or fiber optic cable as the transmission medium. These bases are typically small in size (about 5000 personnel) and represent the majority of Air Force bases. The primary purpose of these bases is to execute strategic, tactical, or military airlift flying missions. The data processing requirements are modest compared to those at an air logistics center, but mission essential data traffic services must survive at least until the flying mission has been completed.

At present the Air Force is enhancing the data processing capabilities by installing new central processors, Sperry mainframe computers of the 1100 series, as part of the Phase IV base data processing installation (DPI) upgrade. Copper pair wiring connects remote data terminal cluster controllers to the central processing unit over a star shaped network. The maximum data rate is limited to 9600 b/s, and desired survivability features are lacking. Another current activity is the procurement of Air Force standard microcomputers and minicomputers. For the most part, these provide a stand-alone data processing capability. To fully utilize the microcomputers and share peripheral equipment, functional organizations must be able to form their own personal computer networks (PCNs). These PCNs will eventually require the capability to be interconnected. The resulting data network should provide improved, survivable connectivity among all base data processing equipment.

Broadband coaxial cable networks have been widely accepted for data distribution within facilities having a high concentration of similar users. In the flying mission base environment, functional areas perform dissimilar tasks, are widely distributed, and may need few (3 to 12) data processing equipment interfaces. Under these circumstances, cost, survivability, and performance advantages favor use of networks that may be better served by an optical fiber transmission plant rather than a coaxial cable transmission plant.

In this report the base environment is modeled, cable plants are designed (both feeder and survivable backbone), and interface equipment is described. The two resulting networks are also priced. The decision of whether a fiber optic or broadband coaxial cable plant is more appropriate to the base environment is based largely on the reader's perception of future (20 years) communication requirements. The coaxial cable plant is favored if multiple channels of analog traffic such as the National Television Standards Committee (NTSC) video will be required. The fiber optic plant is favored if high speed digital traffic (digitized teleconferencing video with encryption) is needed.

Section 2 provides an outline of the objectives that had major impact on the design of the data network.

Section 3 discusses a typical flying mission base. It describes the physical configuration of the base, the density of data processing equipment, a logical approach to segmenting the base into subnetworks, and the existing base wiring as it applies to data transmission.

Section 4 provides a cabling approach for building wiring, subnetwork cabling, and backbone cabling for the model base. This is done for both fiber optic and broadband coaxial cable plants. Cost and survivability issues are discussed therein.

Section 5 describes one network option for each of the cable plants. A network, based on a centralized packet controller (CPC), is used herein for the fiber optic cable plant. Such equipment is represented by AT&T's Information Systems Network (ISN) which will be used for pricing purposes herein. The representative equipment used for pricing a coaxial cable plant network is that manufactured by Ungermann-Bass.

Section 6 summarizes and contrasts the two network approaches and discusses future service options for each approach.

SECTION 2

OBJECTIVES FOR A BASE DATA NETWORK

The flying mission base data network should be a reliable and cost effective means of communications for present and future ADP equipment on a base. As more of the mission essential operations depend on office automation, the need for survivable transmission between functional organizations increases. The principal objectives that influenced the selection and design of the network approaches described in this report are given in table 2-1.

Table 2-1. Base Data Network Objectives

- Provide survivability for mission essential communications
- Monitor and control the network for fault isolation and reconfiguration
- Serve an existing diversity of office automation equipment
- Permit the formation of microcomputer subnetworks
- Provide growth options for future services
- Use existing cable plant where possible
- Minimize cost

How each objective influenced the selection and design of the networks considered in this report is described below:

a. <u>Provide survivability for mission essential communications.</u> Data communications may be impaired by random equipment failures or by sabotage. Sabotage is potentially more disruptive since an attack may be directed to disrupt all base communications if a single point of failure exists.

Sabotage may take the form of physical destruction of a central hub or key transmission lines between hubs. It can also take the form of one or more jammers that garble messages and thereby prevent successful data transmission.

A single point of failure is to be avoided in the design of the data network. An approach to meeting this objective is to break the base into subnetworks, each of which operates independently of all others under stressed conditions. If subnetworks can be formed that correspond to functional organizations having a high rate of internal communications, then segmentation will have minimal effect. In all cases, the maximum level of connectivity between subnetworks should be preserved.

In the base model developed herein, four subnetworks that carry mission essential traffic are defined. Each has its own hub electronics (headend for a coaxial cable plant or packet controller for a fiber optic cable plant). The backbone links between hubs have sufficient redundancy to allow diversity routing around breaks in the transmission medium. Within the subnetwork additional survivability features are incorporated. The inbound data channel can be denied access to the hub if anomalous signal conditions exist as caused by equipment failure or deliberate jamming. These approaches to survivability are considered essential for the two data networks designed herein.

b. <u>Monitor and control the network for fault isolation and reconfiguration.</u> The data communication network extends over large portions of an Air Force base. The main base area over which the network extends is approximately 1 square mile. Other facilities are outside the main base area. Faults can often be isolated within a building by injecting test signals into the cable plant and monitoring the response at downstream points along the cable plant. Manual fault location of this type applied to the widely distributed base network is impractical. Instead, sufficient network monitoring and control must be incorporated into a network manager to allow automatic fault location and denial of network access to failed equipment. To accomplish its functions, the network manager will need to collect network statistics from which traffic loading, retransmission rate, failed transmissions, and connection time can be derived for each port and network segment. Thresholds also need to be established that alert personnel to abnormal and threatening conditions.

By use of monitoring functions and alerts, the operator can locate intermittent failures for timely repair. In addition, if a major fault occurs, the network monitor either on its own or with operator concurrence can respond by means of a reconfiguration. This type of capability is inherent in a packet controller. It is, however, lacking in simple broadband coaxial cable systems. Of late, more systems are offering this capability by adding a workstation as a network manager.

c. Serve an existing diversity of office automation equipment. The base network will require the connection of synchronous and asynchronous terminals, widely used minicomputer backplane interfaces (Unibus and Multibus), and card interfaces to microcomputers such as the IBM-PC or the Air Force standard microcomputer equivalent.

d. Permit the formation of microcomputer subnetworks. A functional area on base may have a number of microcomputers and peripherals that communicate regularly with each other but only occasionally with equipment outside the area. The networking approach should not preclude the formation of such subnetworks. Two benefits occur from the formation of subnetworks. First, traffic within the subnetwork is offloaded from the base-wide network, thereby easing congestion. Second, the subnetwork is more survivable because it extends over a smaller geographical area.

e. Provide growth options for future services. The nature of future service is a matter of speculation. In the case of a broadband cable network, a dual cable rather than a midsplit system is considered. This provides an analog bandwidth of 50 to 400 MHz, which is adequate for multiple RF modulated data channels and multiple analog video channels, each of which utilizes 6 MHz of bandwidth.

A four-fiber cable is being considered for the fiber optic cable plant. Two of the fibers will be dual window multimode fibers, and two will be single mode. At short wavelengths, the multimode fiber permits 10-Mb/s transmission. At a future date selection of long wavelength sources will allow transmission of up to 100 Mb/s over the same multimode fibers. The single-mode fibers are not expected to be used in the near term. The use of single-mode fibers in conjunction with long wavelength LEDs will allow transmission at gigabit rates. The fiber optic cable plant is well suited to a future in which high data rate digital transmission dominates.

f. <u>Use existing cable plant where possible</u>. The use of existing building and interbuilding wiring and ducts has been considered. The possibility of using existing building wiring appears very attractive. The use of this wiring eliminates the expense of cabling from the building wiring closet to each room in the building. The wiring between buildings is inadequate to serve the data network. Therefore, new subnetwork feeders and backbone cables need to be installed.

g. <u>Minimize cost</u>. The cost of broadband coaxial cable and fiber optic cable approaches will be compared in considerable detail. While less expensive interface electronics could be selected for either medium, the ones chosen for costing and configuration comparisons provide future network growth and the desired network management functions.

SECTION 3

TYPICAL BASE ENVIRONMENT

The development of a base cabling plant and network approach requires a realistic model of a typical flying mission base. The most important elements of this model are:

a. The number and relative location of buildings belonging to each functional organization

b. The number of terminals or workstations in each building

c. The information transfer requirements between organizations

d. The extent to which existing wiring within and between buildings can be used for a data network .

Much of this information is available as a result of base surveys. During FY84 three visits were made to Air Force bases (Minot AFB, North Dakota, Charleston AFB, South Carolina, Upper Heyford/Croughton and Alconbury ABs, United Kingdom) to develop base-level information flows, a baseline for existing and planned information systems, and mission analysis of principal base organizations.

The information flows describe all major information transfers on a base, the form of the information, the method of transfer and, where possible, the volume of information transferred. The base mission analysis describes the duties and responsibilities of each base functional area, the use and priority of information received and transferred, and how each functional area fits into and supports the primary base mission.

As a result of the surveys and data from other bases, a map of a representative base can be derived showing the locations of major and subordinate organizations. Also, the number of terminals or microprocessors that each area can utilize can be determined from anticipated information handling needs. Finally, the volume of information transferred can be modeled. This last derivative of the flow analysis is not equivalent to required data rates.

The surveys carried out in FY84 provided no information from which to assess the possibility of using existing wiring for the base data network. In an attempt to partially fill this gap, brief visits were made to Hanscom AFB, Massachusetts, and Pease AFB, Maine, to discuss the cabling plant with representatives of the resident communications squadrons. Two principal conclusions resulted from the visits:

a. Upon initial inspection there appears to be adequate wiring to allow reuse for the data network in many buildings. Much of the 25-pair wiring for key telephones has become surplus with the implementation of the single-line concept. The suitability of this wire for data transmission still must be determined.

b. The outside plant wiring, for the most part, cannot serve the data network requirements. The outside plant is wired in the form of a central star from the base main telephone frame. This wiring topology is incompatible with the need for a survivable decentralized network. In addition, the outside plant is almost fully utilized and has few spare twisted pairs.

3.1 TYPICAL BASE MODEL

Typical locations of functional organizations on a SAC main base area are shown in figure 3-1. The model base represented in the figure has 87 distinct blocks, which correspond to individual buildings. A SAC base is compact, having the main base buildings within an area of approximately 1 square mile (6000 feet by 4000 feet). A tactical air force (TAF) base has a similar structure; however, maintenance and operations facilities are more widely dispersed, being in close proximity to taxiways.

The functional organization (usually a branch) that is represented by each block is identified by an acronym within the block. (See the glossary.) Each block contains a number in the lower left-hand corner. This is the number of terminals, microcomputers, or workstations that are projected to be needed once office automation is incorporated within that functional block. The number is based on survey results of workloads and types of functions carried out within the block.

As can be seen, the number of terminals or microcomputers in most buildings is quite small. Furthermore, this data terminal equipment (DTE) is generally not expected to be clustered but rather widely distributed. For this reason, it is desirable to use existing copper pair wiring for building distribution. The expense of installing a new data transmission medium is not warranted in many buildings.

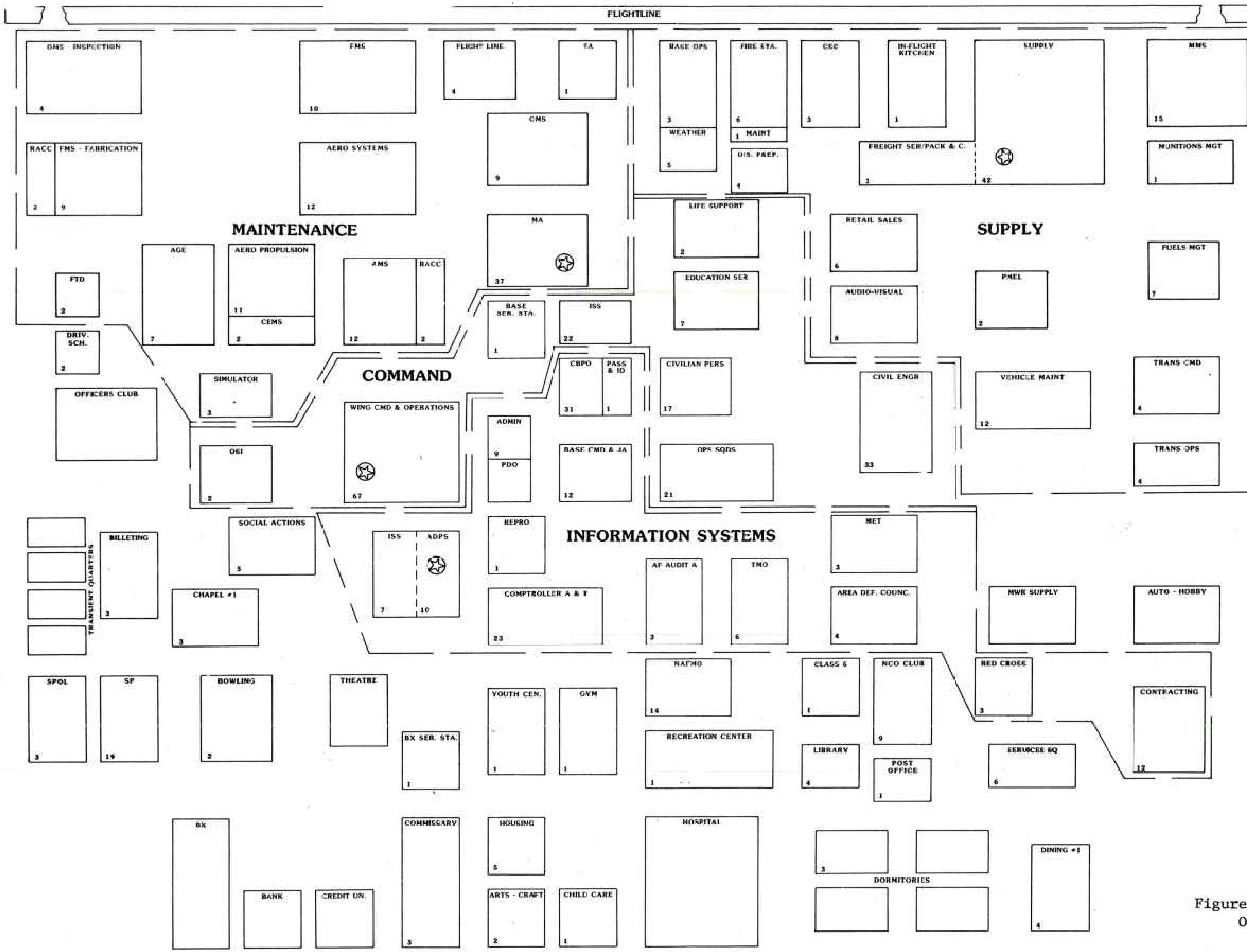


Figure 3-1. Location of Functional Organizations on a Typical SAC Base

The base survey does not distinguish between terminals, microcomputers (personal computers), and workstations. In a 5-year time frame most of the network attachments will probably be microcomputers or workstations. The network will be designed to allow a mix of the following kinds of traffic:

a. Centralized Phase IV computer with remote terminals (2.4kb/s synchronous)

b. Multiple minicomputers within functional organizations with remote terminals (19.2 kb/s asynchronous, RS-232)

c. Clusters of microcomputers throughout the base (communication at 1 Mb/s within the personal computer (PC) network)

d. Isolated microcomputers with occasional data transfers to other microcomputers or minicomputers

e. Interconnections among "a" through "d."

3.2 SEGMENTATION OF THE BASE DATA NETWORK

To improve survivability, the base network has been divided into several subnetworks in which members are grouped according to function. For example, a maintenance subnetwork was formed out of branches that are components of the maintenance squadrons. They include flightline, inspection, propulsion, fabrication, aerospace systems, and avionics branches. By such grouping, heavy intersquadron communication is concentrated within the subnetwork.

The maintenance subnetwork is shown in the upper left-hand portion of the SAC base shown in figure 3-1. It consists of 13 buildings with a total of 127 DTEs. Three other subnetworks have also been defined: supply, command, and information systems. To include all organizations that require real-time survivable (or mission essential) communications into one of the four subnetworks, some were assigned on the basis of proximity to the subnetwork. For example, the fire station is incorporated into the supply subnetwork. Each subnetwork has a central hub that is identified by a star within a circle. The characteristics of the subnetwork are given in table 3-1.

Table 3-1. Base Subnetworks

Organization	Number of Buildings	Number of DTEs
Maintenance	13	127
Supply	15	127
Command	9	172
Information Systems	12	72

A considerable number (38) of blocks are outside the mission essential subnetworks. The hospital is a specialized facility having a high density of terminals, patient monitoring equipment, and video generation and receiving equipment. Its internal communications may be well served by installation of a broadband coaxial cable distribution plant with a local headend. This application will not be addressed herein.

The remaining areas do not require real-time military survivable communications. Some have only one or few terminals and handle a low volume of data traffic. Cost factors alone will determine if a fifth subnetwork should be formed to include these organizations or if they may be connected using a telephone or short-haul digital modems connected through the telephone dial central office.

3.3 MAINTENANCE SUBNETWORK

The maintenance organization has been selected for development of competitive subnetwork implementations. Both a broadband coaxial cable plant and a fiber optic cable plant will be designed and priced for this subnetwork. Also the number of interface units, concentrators, and hub characteristics will be selected to accommodate the maintenance subnetwork. The total base network will be modeled as equivalent to four maintenance subnetworks plus the backbone used to interconnect subnetworks.

SECTION 4

CABLING APPROACH

The cable plant that serves the data communication needs of a base includes building wiring, subnetwork feeders, and an interconnection backbone. These parts of the cable plant are shown in figure 4-1. Portions of the data cable plant may parallel and therefore be integrated with a distributed voice network. The backbone is the most likely candidate for this integration.

4.1 BUILDING WIRING

As described in section 3, it will be assumed that the near term data communication requirements are met using the existing copper pair wiring within each building. This approach is warranted by the anticipated low density of DTE throughout a typical building. Should clusters of DTE occur, these are most easily served by extending the subnetwork trunk to the cluster location. In the typical case, the subnetwork feeders are terminated in the building wiring closet where the appropriate interface unit (IU) between the feeder network and DTE is located.

The wiring closet, or an immediately adjacent area, will have to provide a hospitable environment with a source of electrical power for the IU. The output of the IU may be an EIA interface such as the RS-232, which limits maximum transmission distance to 50 feet. In this case, an inexpensive (less than $100 per unit) short distance modem (SDM) is used to condition the signal for transmission up to several thousand feet without causing interference on adjacent copper pairs carrying voice traffic. Other possible outputs of the IU, such as the StarLAN signaling, are already suitable for transmission over copper pairs at rates of 1 Mb/s (appendix A).

Figure 4-2 depicts a typical wiring closet installation. Mounted on the left-hand side of the entry panel is the existing building frame that connects the voice twisted pair feeder to the building copper pair wiring. To accommodate the data network, the subnetwork feeder is terminated and connected to the IU. The output of the IU is conditioned as required and feeds the building frame. Required connections are made within the building frame.

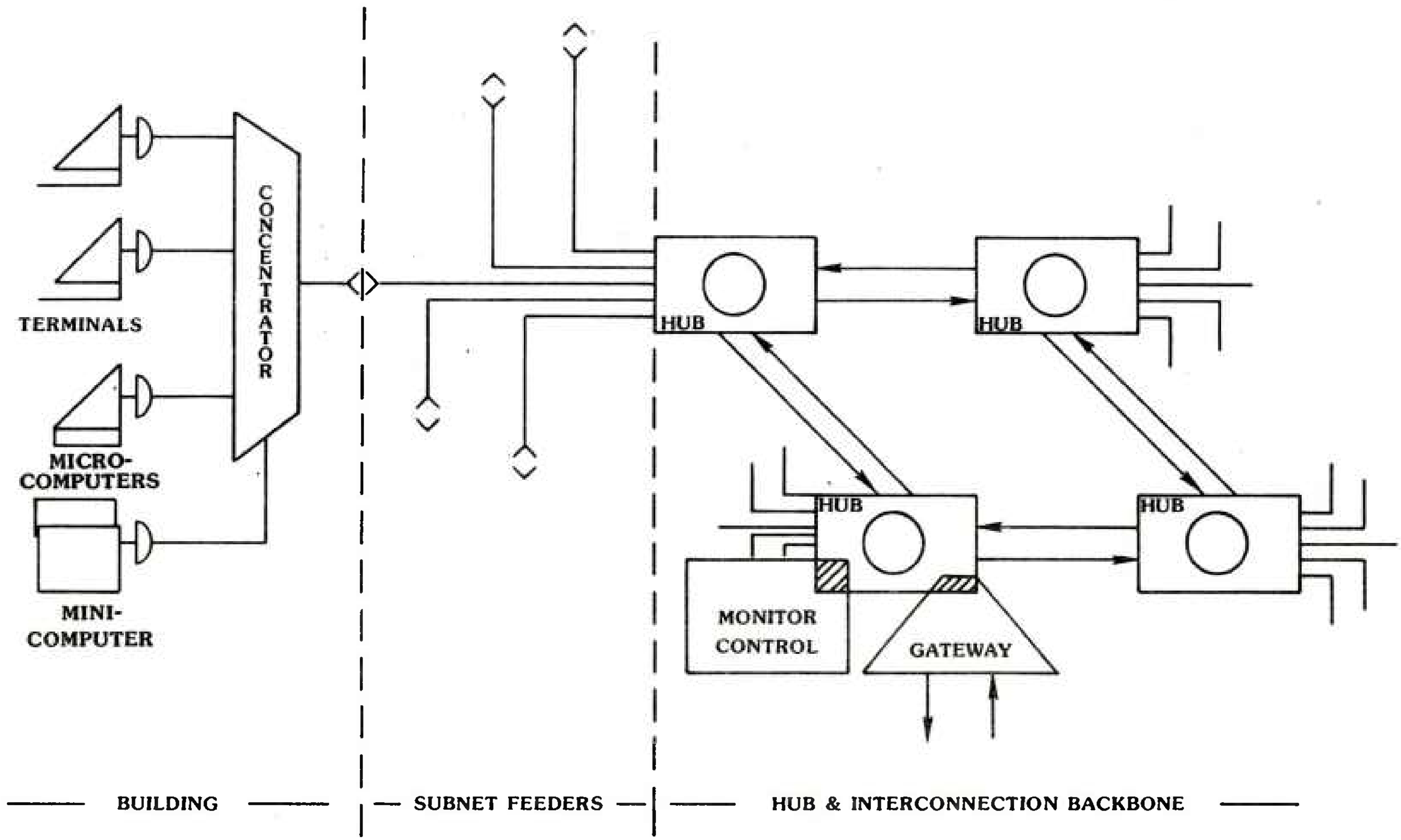


Figure 4-1. Base Cable Plant Organization

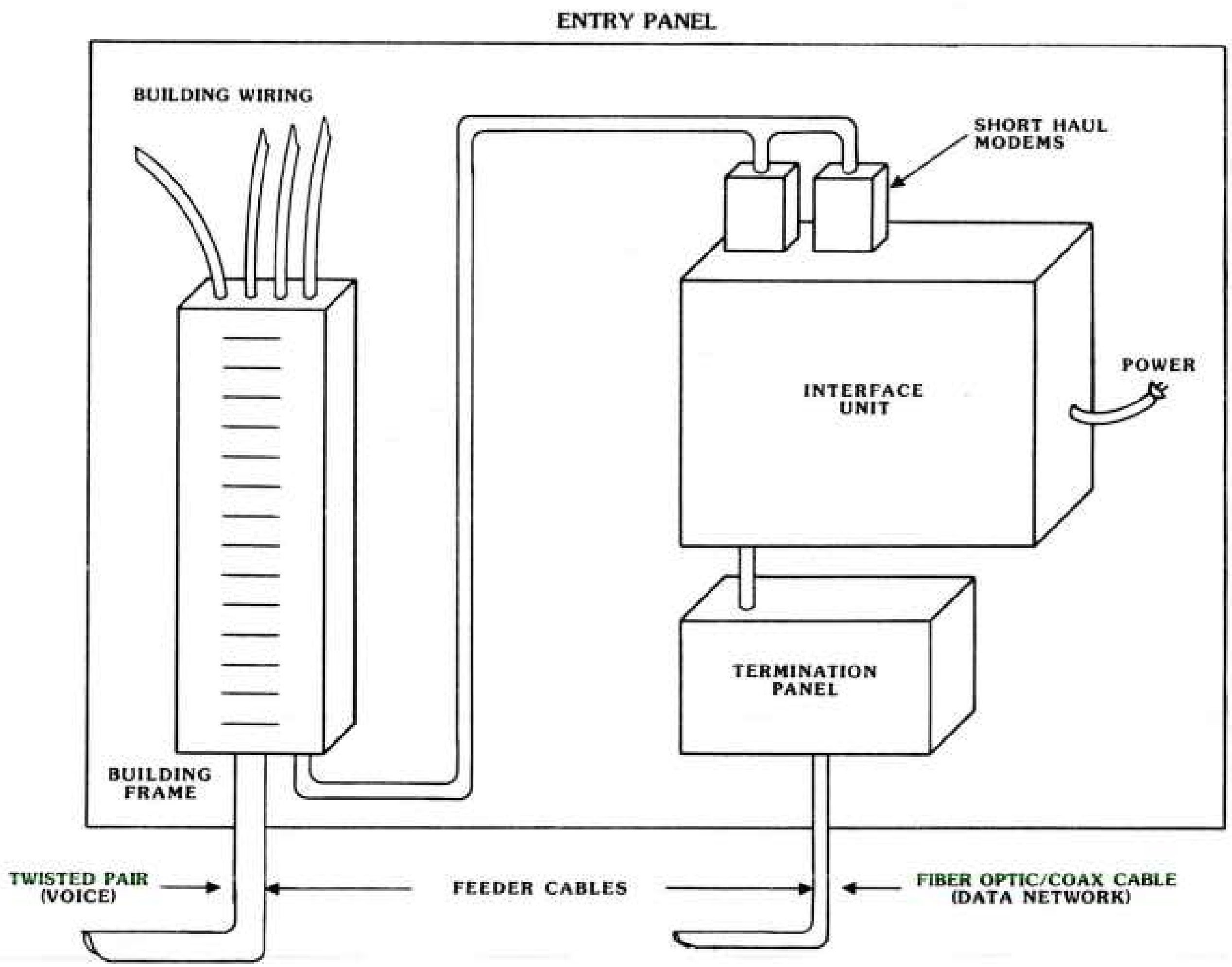


Figure 4-2. Building Entry Panel

The building wiring will not be included in the cost of installing any of the networking approaches. The cost of the termination panel, IU, and SDM will be included under the pricing of specific implementations.

4.2 SUBNETWORK FEEDERS

The subnetwork feeders may be implemented using fiber optic cable (star or ring topology), broadband cable (bus or tree topology), or twisted pair cable (star topology). The selection of the transmission medium does not imply selection of an access protocol. For example, a broadband bus may use token access or contention access.

The stated objective of meeting near term requirements at minimum cost needs to be tempered so that the selected network can satisfy future transmission needs. In the case of broadband cable, a dual cable plant rather than a single midsplit cable plant will be considered. Capacity is doubled at an increased cost for materials of approximately 25%. Similarly, a fiber optic cable plant having four fibers to each building will be considered rather than the two fibers immediately required. The increased cost for the four-fiber rather than the two-fiber cable option is approximately 30%. When installation costs of trenching are included, these expanded capability options add little to the overall cost of the installed cable plant.

The subnetwork feeder to be considered in this section is that associated with the maintenance organization. In terms of number of areas or buildings served and the number of terminals or workstations interconnected, it is representative of the four base subnetworks.

4.2.1 Fiber Optic Cable Feeders

Two approaches to designing a fiber optic cable plant will be considered. The first approach uses a continuous length of cable from each of the 12 outlying buildings back to the 13th building in the maintenance organization where the hub of the subnetwork is located. Figure 4-3 shows the routing of the cables along the grid defined by base roadways. As cables come together, they are buried in a common trench. The number of cables in a trench at points along the trunk are given by the number over an oval around the trunk, as shown in figure 4-3. At the hub, the 12 cables from the remote buildings of the subnetwork and the local building connection come together to feed a central distribution panel. Into this panel are also brought the cables that serve as the backbone between hubs.

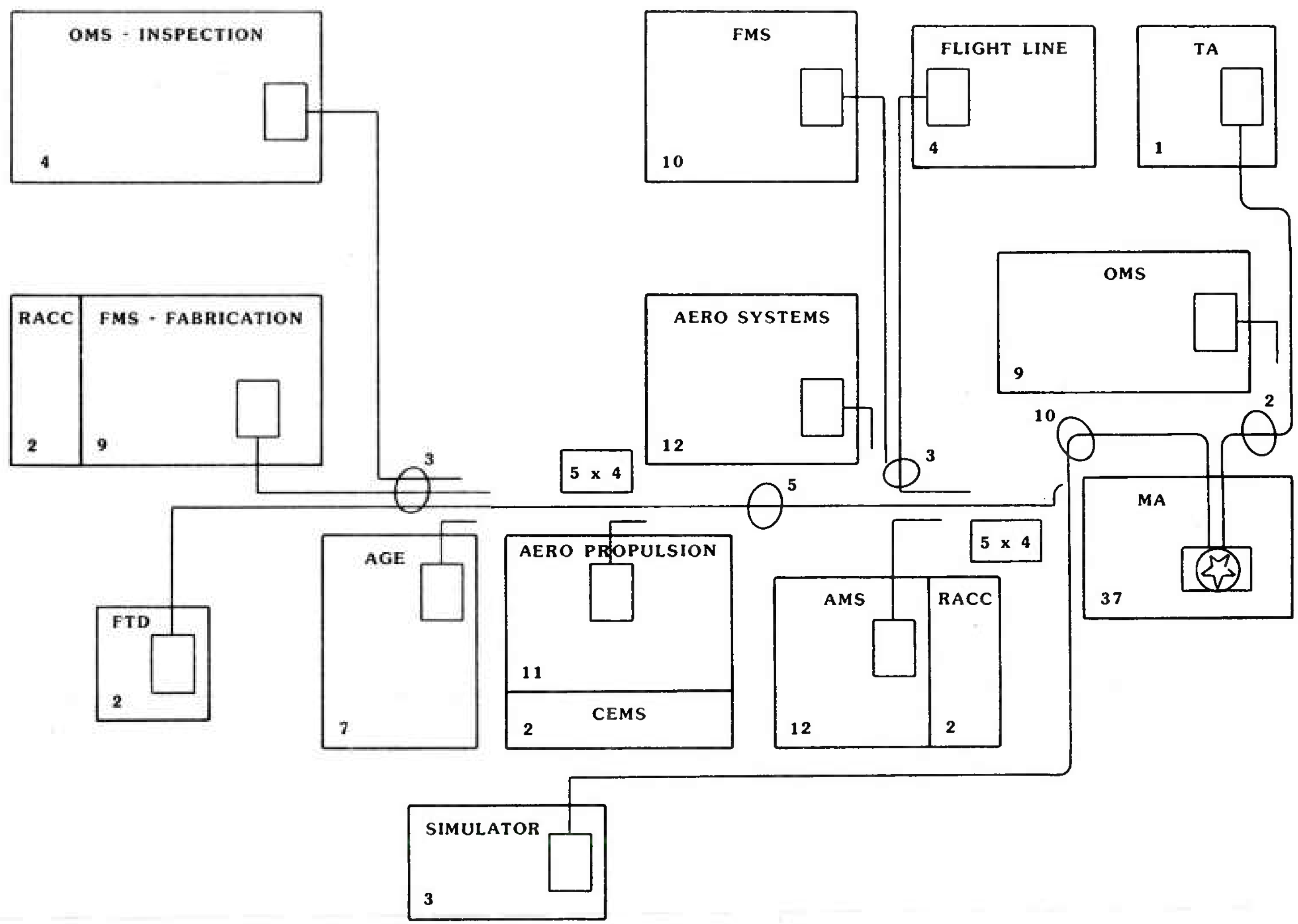


Figure 4-3. Fiber Optic Subnetwork Feeder

An alternative cable plant uses feeder cables having a large number of optical fibers spliced to smaller cables at appropriate points along the trunk. Two possible splice locations are shown in figure 4-3. This alternative saves cable cost but incurs costs for splicing equipment and labor. For simplicity of installation the first alternative is preferred. The cost consequences of both approaches will be addressed in this section.

The length of cable between the entry panel in each building in the maintenance organization and the subnetwork hub is given in table 4-1.

Table 4-1. Cable Lengths (Organization to Hub)

Organization	Cable length (meters)	
OMS - Inspection	963	Group I
FMS - Fabrication	810	Group I
FTD	891	Group I
AGE	666	Group I
Aero Propulsion	567	Group I / Group II
Simulator	810	Group II
FMS	540	Group II
Aero Systems	396	Group II
AMS	378	Group II
Flight Line	567	Group II
TA	315	
OMS	243	
MA	0 (Hub Location)	
Total	7,146	

The maximum cable length is 963 meters. The maintenance area of a SAC base is more compact than other defined subnetworks. Therefore, in the following analysis, it will be assumed that the maximum point-to-point distance to outlying facilities within any subnetwork on a TAF base or over the backbone is 2 km.

4.2.1.1 <u>Feeder Termination Equipment</u>. At both the building entry panel and at the hub, provision must be made to terminate the optical fiber cable. Figure 4-4 shows some details of one termination approach. The fiber optic transceivers are contained within the IU

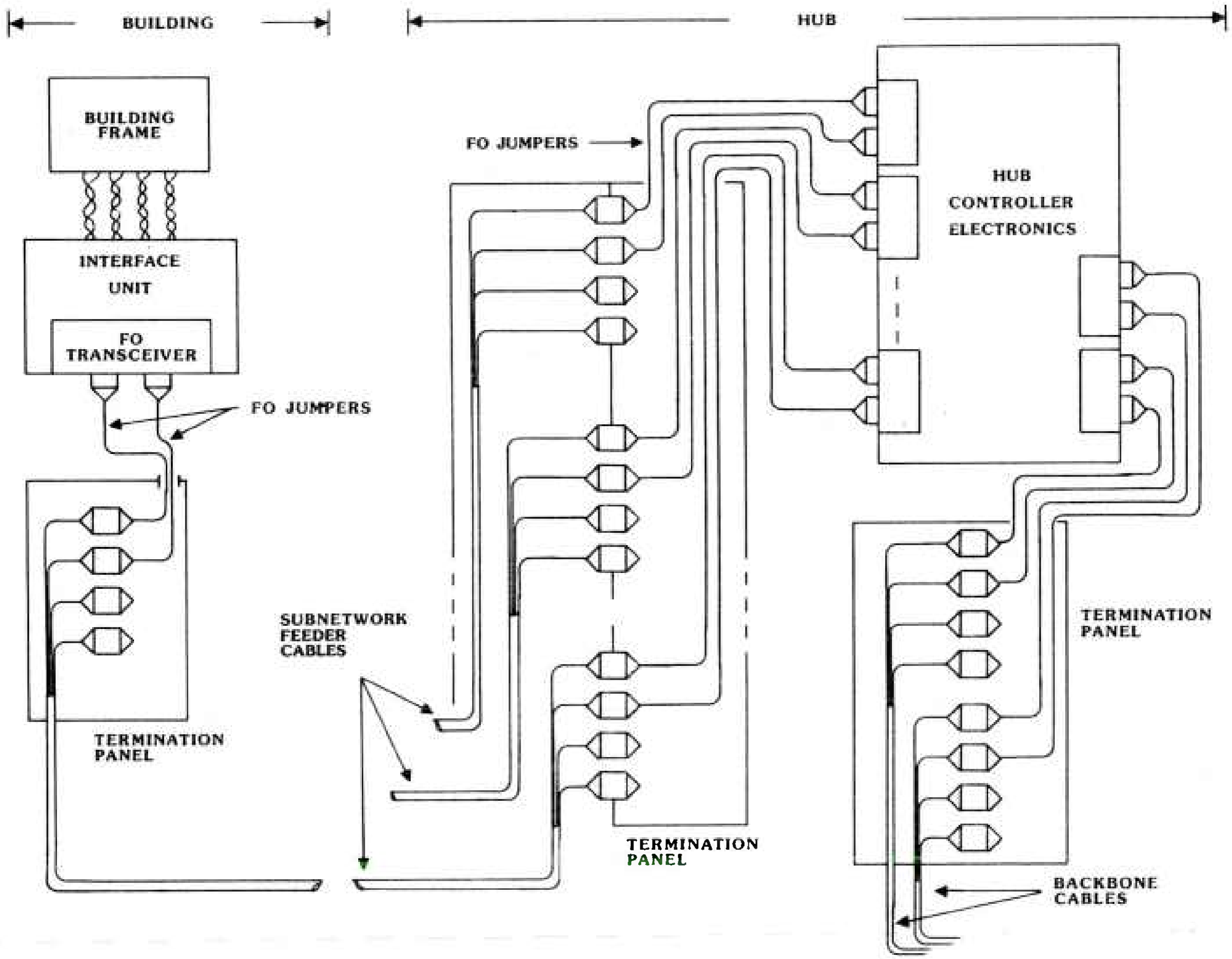


Figure 4-4. Hub and Building Termination Equipment

and hub electronics. To provide a high degree of flexibility, termination panels are used at each end with short fiber optic jumpers to the IU or hub. To terminate the fiber cable, connectors rather than splices are recommended to ease troubleshooting and allow reconfiguration of the network by personnel with a low skill level. Note that each simplex fiber channel has at most four connector pairs in series.

An estimate of component costs for implementing the maintenance subnetwork feeder is given in table 4-2.

Table 4-2. Fiber Optic Subnetwork Feeder Costs

Component	Number Required	Unit Cost	Total
Remote Termination			
Panel	13	$41.00	$ 533
FO Jumpers	26	74.00	1,924
Couplers	26	10.25	267
Hub Termination			
Panel	1	268.00	268
FO Jumpers	26	74.00	1,924
Couplers	26	10.25	267
Subnetwork Feeders			
Cable (4 fiber)	7,146 m	3.75/m	26,798
Connectors	52	14.25	741
Labor	13 h	50.00/h	650
Trenching	2,493	4.00/m	9,972
		Total Cost	$43,344

The cable selected is a four-fiber cable having two single-mode fibers and two multimode fibers with core and cladding dimensions of 62.5/125 or 85/125 µm. AT&T's ST series multimode connector is chosen for cost comparisons. This low cost, high performance connector is reported to provide a mean loss of 0.22 dB with a standard deviation of 0.15 dB.[1] The connector uses a keyed butt design. Connector pricing includes connector cost plus expendables such as epoxy and polishing compounds. Assembly time is less than 15 minutes in single-unit fabrication.

Remote and hub termination panels are used to house the coupling between connectorized fibers and to store loops of fiber between cable breakout and connector. The panels have been selected to provide adequate space to mount couplers for both multimode and single-mode fibers. However, no cost provision has been made for connectorizing the single-mode fiber at present. The fiber will simply be coiled up for use when future applications arise in 3 to 5 years.

The required trenching length is shorter than the total length of cable since several cables will share the same trench.

4.2.1.2 Optical Fiber Selection. Several factors influence the selection of the fiber type to be used in the cable. The factors include link loss budget, coupling efficiency to electro-optic sources, link bandwidth, and cost of electro-optic sources.

Link Loss Budget. A simplified link budget follows:

$$T_x - R_c = A_f + A_c + A_s + P_{bw} + M$$

where

T_x	=	transmitter optical power in dBm
R_c	=	receiver optical power in dBm for a 10^{-9} BER
A_f	=	fiber attenuation
A_c	=	connector attenuation
A_s	=	splice attenuation
P_{bw}	=	the power penalty due to bandwidth limitations
M	=	the operating and repair margins

The optical power T_x coupled to a fiber depends on the type of source (ILD, edge emitting LED, or surface emitting LED), optical fiber core diameter, and numerical aperture. Table 4-3 provides a link loss budget with resulting margin M for three cases of interest: an inexpensive short wavelength link for 10-Mb/s transmission, a long wavelength link for 100-Mb/s transmission, and a single-mode link for greater than 100-Mb/s transmission.

Table 4-3. Link Loss Budget

Transmitter/Rec	A	B	C
Data Rate (Mb/s)	10	100	>100
Wavelength (nm)	0.820	1.300	1.300 SM
Transceiver Cost 1985	$75	$600	$2,900
Fiber Type	85/125	85/125	8/125
T_x (dBm)	-17.6	-17	-26
R_c (dBm)	-34	-30	-40
A_f (2 km) (dB)	7	3	1
A_c (4 pair) (dB)	3	3	2
A_s	0	0	0
P_{bw}	1	1	0
M (dB)	5.4	6	11

Notes: A = American Photonics: TR 1000C LED/PIN
B = Sumitomo Electric: DM-56, LED/PIN
C = Lasertron: QLED 1300 SM, PINFET QDFT

All three examples result in a link margin M greater than the 3 dB considered necessary for variations due to temperature and aging. This loss margin is a direct result of the selection of a large core multimode optical fiber (85/125) or (62.5/125). Power coupled from an LED source is inversely proportional to the square of core diameter and the square of numerical aperture (NA). The 85/125 fiber with an NA of 0.26 provides 6.9 dB increase in optical coupling compared to commonly used 50/125 fiber with an NA of 0.20.

Fiber loss for 2 km of multimode fiber is taken from the specification of middle-grade Corning dBF™[2] fiber. The connector loss of 0.75 dB per connection exceeds the mean plus three standard deviation loss of the ST connectors. The loss for single-mode connectors is projected for 3 to 5 years when the extra capability offered by this medium is first utilized in the base environment.

Splice loss is zero in this subnetwork feeder case since a continuous cable is run from the building termination panel to the hub panel. The P_{bw} is the equivalent power penalty due to inadequate fiber optic bandwidth that results in pulse dispersion sufficient to cause intersymbol interference. System designers typically avoid a power penalty exceeding 1 dB by using sources and transmission media having adequate bandwidth. The system described below meets these criteria.

As can be seen from the table, meeting the link budget with adequate margin over the short distances anticipated in the subnetwork feeder applications is not a problem. Note that no active components are required between the buildings and the hub. This is not true in the case of a broadband coaxial cable feeder.

Link Bandwidth Requirements. Dispersion is the broadening in time of an optical signal pulse as it propagates down a fiber. The minimum required optical power for signal detection is obtained for very narrow optical pulses input to a receiver. For dispersion broadened pulses, the additional optical power needed for detection can be defined as a power penalty. This is the excess power needed to overcome the effects of intersymbol interference. If the rms width of the pulse is less than 0.25 of the symbol time, the power penalty is less than 1 dB. This result has been obtained analytically and verified experimentally by Personick.[3] For a Manchester encoded signal the symbol time is 0.50 of the bit interval. Therefore, to maintain a power penalty of less than 1 dB

$$\sigma \leq (0.25)\,(0.50)\,T$$

where

σ = the rms pulse width
T = the bit interval

For a Manchester encoded signaling rate of 10 Mb/s, a tolerable value of the pulse broadening due to optical fiber dispersion is $\sigma = 12.5$ ns. The dispersion characteristics of optical fiber are usually described in terms of fiber bandwidth. The optical fiber bandwidth that corresponds to this maximum dispersion is found by means of the Fourier transform of the Gaussian rms pulse width

$$BW = \frac{0.187}{\sigma} \quad .$$

For an rms pulse width of 12.5 ns, BW = 15 MHz. Thus, the minimum distance bandwidth product of the optical system must exceed 15 MHz. To allow adequate performance with less than optimum receivers and non-Gaussian pulse shapes a fiber link bandwidth objective of 20 MHz is adopted herein.

Optical System Bandwidth Performance. Optical fiber bandwidth is limited by both intramodal dispersion and intermodal dispersion. Intramodal dispersion is due to the variation of propagation velocity in a fiber optic waveguide as a function of source wavelength and linewidth. LED optical sources emit radiation over a wide spectral region (typically Gaussian in shape) characterized by the full width half maximum (FWHM) linewidth of the optical power. The FWHM of a typical LED is 0.040 μm at 0.820 μm and 0.095 μm at 1.300 μm.[4] The derivative of the propagation velocity with wavelength is relatively large at 0.820 μm and reaches a minimum near 1.300 μm. Intramodal dispersion can be determined from

$$D(\lambda) = \left[C_1 \lambda_o - C_2 \lambda_o^{-3}\right] \quad \frac{\text{ns}}{\mu\text{m} \bullet \text{km}}$$

where

the values of constants C_1 and C_2 for 85/125 fiber are[2]

$C_1 = 24.9144$
$C_2 = 79.0819$

and

λ_o = center wavelength (μm)

Table 4-4 lists the linewidth, Δλ, dispersion, D, and the equivalent intramodal bandwidth using the conversion from FWHM Gaussian pulse width to equivalent bandwidth (BW = 440/D•Δλ).

Table 4-4. Intramodal Dispersion Effects

Line Center λ_o (μm)	Line Width Δλ (μm)	Dispersion D (ns/μm•km)	BW_{intra} (MHz•km)
0.820	0.040	123.00	89.4
1.285*	0.095	5.26	880

*1.285μm is 0.050 μm displaced from the intramodal dispersion minimum (1.335 μm) of the 85/125 fiber.

Optical signals propagating in multimode fiber also suffer intermodal dispersion. Differences in the velocity of propagation among the many modes result in additional signal dispersion. The magnitude of the intermodal dispersion depends on how well the refractive profile of the fiber approaches an ideal parabolic profile. The effect is independent of optical source linewidth. Intermodal dispersion does not occur in single-mode fibers since only the lowest order axial mode propagates. Manufacturers typically specify the value of intermodal dispersion in terms of fiber bandwidth (BW_{inter}).

The composite effect of intramodal and intermodal bandwidth is the effective bandwidth (BW_{eff}) that is computed as follows:

$$BW^{-2}_{eff} = BW^{-2}_{inter} + BW^{-2}_{intra} .$$

Table 4-5 provides effective bandwidth for some cases of interest. The effective bandwidth of the fiber is also given for the 2-km maximum link distance.

Table 4-5. Effective Bandwidth of Fiber Optic Links

Source Line Center (µm)	BW_{intra} (MHz•km)	Fiber Type Core/OD	BW_{inter} (MHz•km)	BW_{eff} (MHz•km)	BW_{eff} (2 km) MHz
0.820	89.4	85/125	200	81.6	40.8
1.285	880	85/125	600	496	248
1.285	880	8/125	NA*	880	440

*Single-mode fiber (no intermodal dispersion).

As can be seen from the table, the bandwidth provided for a subnetwork feeder of maximum length (2 km) is more than adequate for near term signaling rates of 10 Mb/s when 85/125 optical fiber and inexpensive short wave (0.820 µm) sources and detectors are used. The same optical fiber will also serve intermediate requirements with signaling rates to 100 Mb/s by selection of somewhat more expensive long wavelength (1.300 µm) sources. Of course, the fiber can be used for transmission of both wavelengths simultaneously. This technique is referred to as wavelength division multiplexing (WDM).

The extra single-mode fiber pair is intended for future applications. The use of single-mode fiber will allow considerable expansion of transmission bandwidth. The example in table 4-5 yielded a bandwidth of 880 MHz•km. That is a very conservative estimate. If the LED optical source radiation is more closely centered near the intramodal dispersion minimum, a bandwidth as high as 1700 MHz•km may be achieved. Such high bandwidth may find use in the future for the transmission of multiple channels of digital video.

4.2.1.3 Alternate Feeder Cable Plant. Thus far, discussion has centered on a feeder plant in which a cable is run directly from each building to the subnetwork hub. It is also possible to splice many of the four-fiber cables into a single large fiber optic cable at points where they join a common trench. Two possible splice locations are indicated in figure 4-3. The locations are near Aero Propulsion where 5 cables (20 fibers) may be joined (group I, table 4-1) and near RACC where another 5 cables may be joined (group II, table 4-1). The large cable formed near Aero Propulsion simply bypasses the splice point near RACC. Thus, each fiber is spliced only once between end points.

The distance from splice point to hub for group I is 495 m, and for group II is 225 m. Thus, the reduction in the length of four-fiber feeder cable is 3600 m (5 x 495 m + 5 x 225 m). The length of 20-fiber cable is 720 m (495 m + 225 m). Additional splice components and labor are needed. The revised cost for the subnetwork feeder cable is given in table 4-6.

Comparing the cabling costs in tables 4-2 and 4-6 shows that, for the short link distances on a base, splicing groups of feeder cables into a larger cable results in minimal cost savings. For ease of installation into open trenches, burying a continuous cable from each subnetwork building to the hub is preferable. This avoids the need for scheduling specialized tradesmen during installation. One benefit of splicing is the smaller resulting cable cross section. In areas where existing ductwork can be used, installation of a single large count fiber cable is preferable to installation of a multitude of four-fiber cables.

Table 4-6. Alternate Fiber Optic Subnetwork Feeder Costs

Component	Number Required	Unit Cost	Total
Remote Termination			
Panel	13	$41.80	533
FO Jumper	26	74.00	1,924
Couplers	26	10.25	267
Hub Termination			
Panel	1	268.00	268
FO Jumpers	26	74.00	1,924
Couplers	26	10.25	267
Subnetwork Feeders			
Cable (4 fiber)	3,546 m	3.75/m	13,298
Cable (20 fiber)	720 m	12.30/m	8,856
Splice Cases*	2	250.00	500
Splice Labor*	80 h (2 men)	50.00/h	4,000
Connectors	52	14.25	741
Labor	13	50.00/h	650
Trenching	2493 m	4.00/m	9,972
	Total Cost		$43,200

*Based on installation experience of approximately $120/splice.

4.2.2 Broadband Coaxial Cable Feeder

Feeder requirements may be satisfied using 75-ohm dual cable broadband bus technology. Figure 4-5 is a simplified diagram illustrating the principal components of a dual cable plant and headend. Each bus interface unit (BIU) transmits signals on an inbound cable and receives signals on an outbound cable. The BIU is connected to the cable plant through multiport taps on inbound and outbound cables. The multiport taps considered herein provide eight taps for connecting several BIUs, video sources, and test signals. All unused taps are terminated.

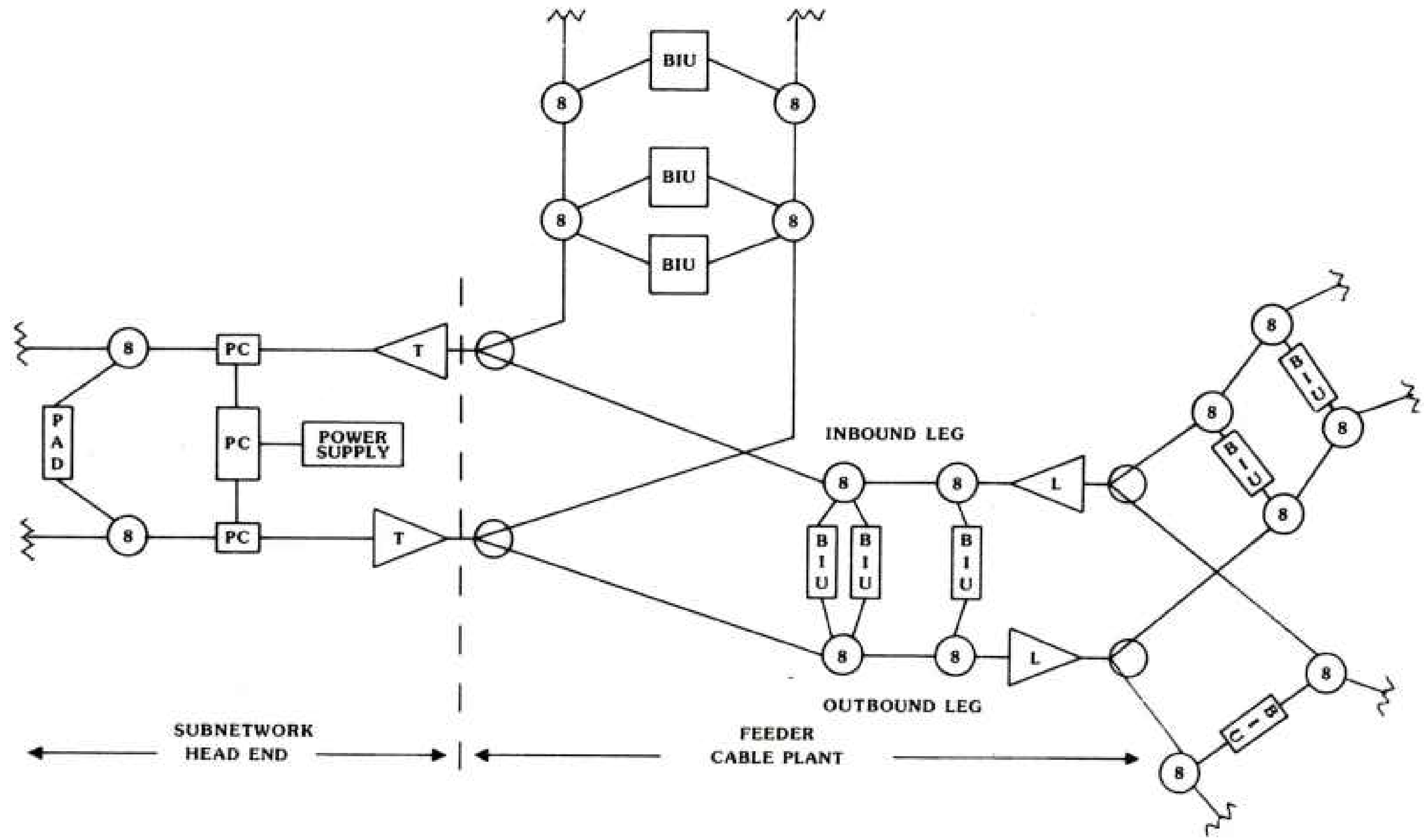


Figure 4-5. Dual Coaxial Cable Broadband Subnetwork

The dual cable plant forms a tree topology in which branches are joined together by signal splitters/combiners. At appropriate points, when link margin requirements dictate, amplifiers are inserted. The cable plant converges to a single cable at the headend. The headend shown has the minimum functional capability of transferring signals on the inbound cable to the outbound cable and of providing power to trunk and line extender amplifiers.

In a broadband cable plant the analog bandwidth of each cable extends from 50 to 400 MHz. This bandwidth is split into 6-MHz channels. The channels correspond to the use of this medium for NTSC television video distribution. Data input to a BIU from attached DTEs are packetized. Upon transmission, a digital data stream modulates a radio frequency (RF) signal. The RF signal bandwidth is constrained to fall within a 6-MHz channel or a fraction thereof. When a BIU is designed for use in either a midsplit cable system or dual cable system, the transmission frequency band is different from the receive frequency band. Its operation requires the installation of a frequency translator at the headend.

Cable plants are primarily designed for installation within office buildings where hundreds of DTEs are distributed around the building. The MA building in the maintenance subnetwork may benefit from a building-wide cable plant. However, there is a potential to serve most of the subnetwork members with a multiport tap in the building wiring closet. From there, DTEs may be attached via copper pairs. For now, it is assumed that the coaxial feeder network extends from the hub to the building wiring closet where the BIU interface is located.

An approach to implementing a broadband coaxial cable feeder in the maintenance subnetwork is shown in figure 4-6. The cable plant follows the grid defined by base roadways. Cable is buried so that all active (amplifier) or passive (power divider, equalizer, and connectors) components are located within a building wiring closet or an above ground access panel. The network has three principal concentration points: the headend (A) and two access panels (B and C). Unlike the fiber optic feeder plant, amplifiers must be provided at a number of points along the cable plant.

The lengths of coaxial cable between buildings, access panel, and headend are given in table 4-7. These cable lengths need to be multiplied by a factor of two in estimating material requirements for a dual cable plant.

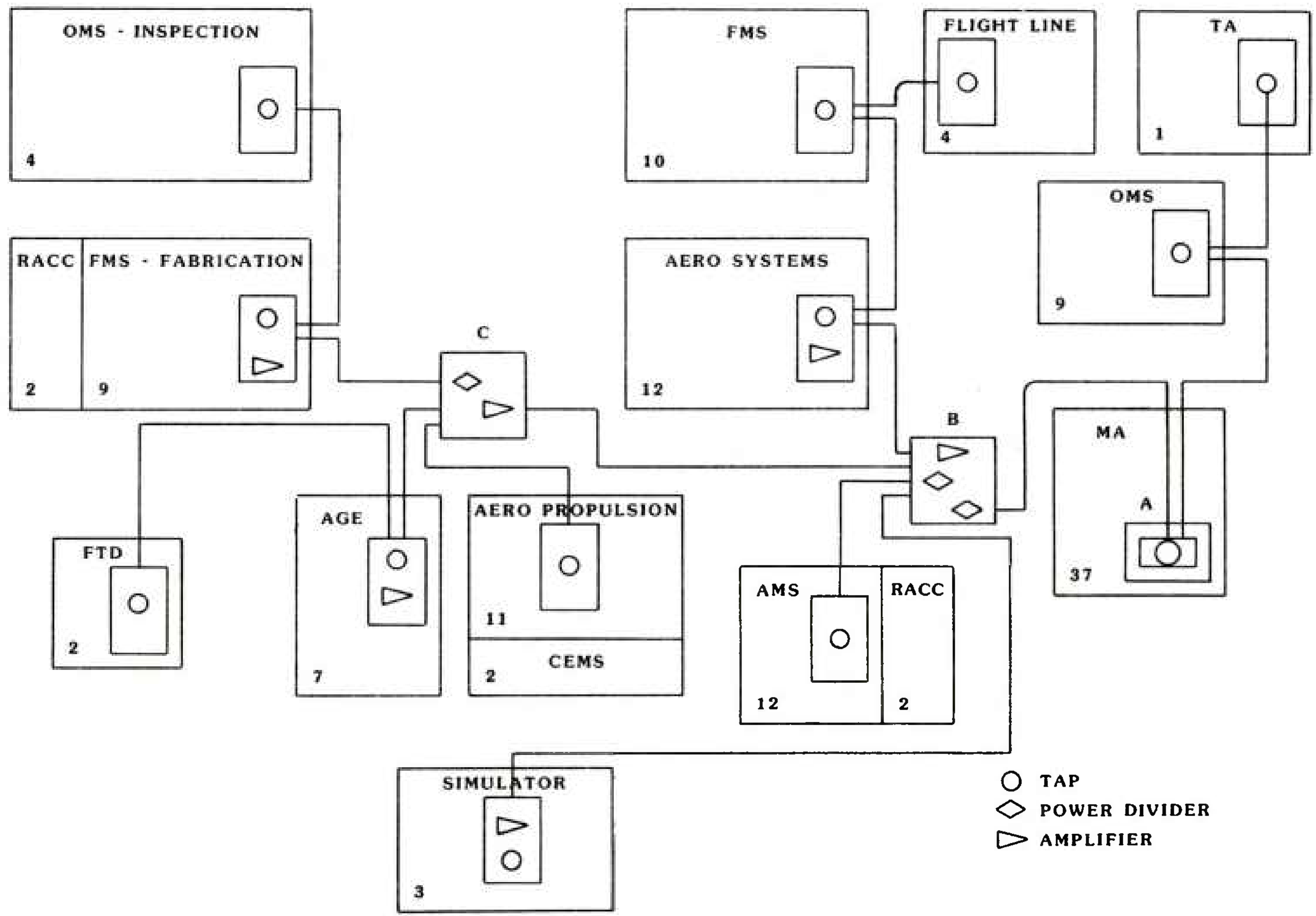


Figure 4-6. Coaxial Cable Subnetwork Feeder

Table 4-7. Coaxial Cable Length (Single Cable)

From	To	Distance (m)	Cable OD (inch)
TA	OSM	117	0.50
OSM	A	261	0.75
FLIGHTLINE	FMS	72	0.50
FMS	AERO SYS	216	0.50
AERO SYS	B	135	0.50
AMS	B	108	0.50
SIMULATOR	B	585	0.75
A	B	351	0.75
C	B	306	0.75
OMS-INSP	FMS-FAB	243	0.05
FMS-FAB	C	207	0.05
FTD	AGE	270	0.05
AGE	C	90	0.05
AERO PROP	C	90	0.05
	Totals	1548	0.50
		1503	0.75

4.2.2.1. Coaxial Cable Size Selection. The cables and multiport taps of a coaxial cable system have losses that increase with increasing signal frequency. The coaxial cable loss itself increases with the square root of frequency. The difference in loss between the low and high frequencies propagating on a cable is called slope. To compensate for signal slope, equalizers attenuate low frequency signals to match the level of the high frequency signals.

If high signal-to-noise and low levels of intermodulation products are to be preserved, signals must be amplified after approximately every 20 dB of attenuation. For long cable runs where insertion of additional amplifiers is not desirable, a larger diameter cable having lower loss must be selected. The loss parameters of coaxial cables is given in table 4-8. Only armored cables are considered for this direct burial application.

Table 4-8. Coaxial Cable Loss and Cost

Cable OD (inch)	Loss/km @ 400 MHz	Loss/km @ 50 MHz	Cost/m*
0.50	50.2 dB	17.7 dB	$1.25
0.75	34.8 dB	12.5 dB	2.14

*Cost for armored cable for direct burial.

4.2.2.2. Inbound Feeder Design and Cost. Methodologies for pricing convention cable plants exist, but they may give erroneous results for a feeder network. The design of the inbound leg of a coaxial cable plant was undertaken to permit a greater degree of confidence in the pricing for the feeder cable. The design is shown in figure 4-7.

It is assumed that the input to each multiport tap is 45 dBmV. The number above each tap indicates the nominal coupling ratio to the main line. To this must be added device insertion loss. Each intermediate tap or signal combiner is preceded by an equalizer to compensate for cable slope. Main lines are provided with trunk amplifiers (T). No more than one line extender amplifier (L) occurs in any signal path. Signal levels in dBmV at points along the inbound cable are given below the cable adjacent to the cable plant components.

Figure 4-7 shows the location of headend (A) and the contents of the two cable access housings (B and C). The four segments for which 0.75-inch cable was selected are also identified. Finally, the organizational code where each multiport tap is located is identified below the tap. If an outbound cable plant were designed, the cable runs would remain the same. However, amplifiers may be eliminated or located elsewhere. This pricing exercise assumes that the inbound and outbound cable plant have the same material costs. Table 4-9 provides a cost breakdown of the maintenance subnetwork feeder using coaxial cable.

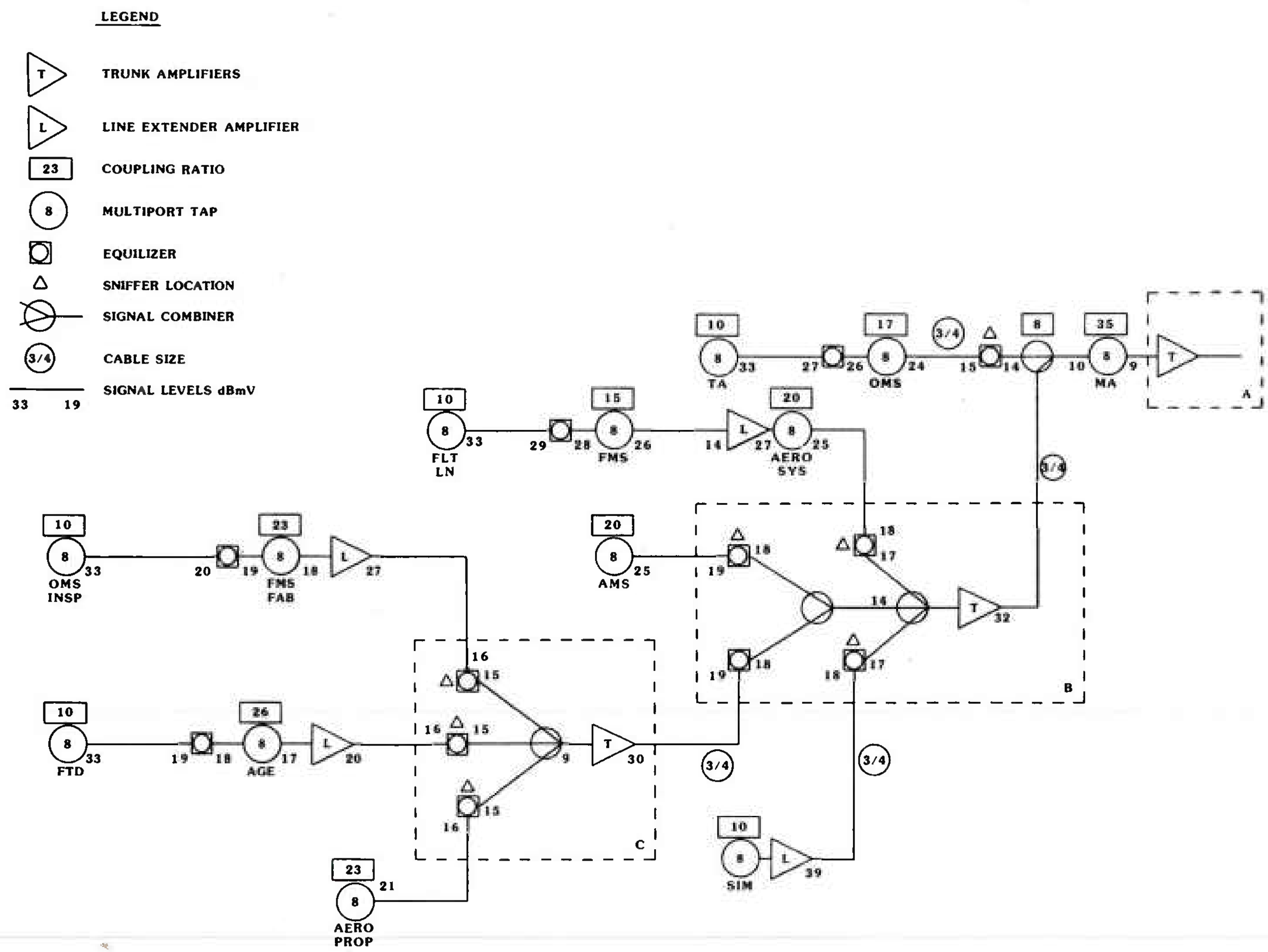


Figure 4-7. Maintenance Subnetwork Inbound Leg

Table 4-9. Dual Coaxial Cable Feeder Subnetwork Costs

Component	Number Required	Unit Cost	Total
Cable (0.50)	3,096 m	$1.25/m	$3,870
Cable (0.75)	3,006 m	2.14/m	6,432
Amplifier (Trunk)	4	952.00	3,808
Amplifier (Line Extender)	8	248.00	1,984
Feeder line Equalizer	24	18.00	432
Signal Splitters	8	36.00	288
Multiport Taps	26	20.00	520
Connectors	100	5.50	550
Terminations	200	2.50	500
Pads	50	10.00	500
Head End			
Amplifier	2	952.00	1,904
Multiport Taps	4	20.00	80
Power Combines	3	26.00	78
Power Supply	1	173.00	173
Trenching	2,493 m	4.00/m	9,972
Pedestal and Access Panel A & B	2	1500.00*	3,000
Cable Connectorization	25 h*	50/h	1,250
	Total		$ 35,341

*Estimated values.

This is a basic cable plant. Depending on the BIUs selected and survivability requirements, other components will be required at the headend. These include a server to download software to BIUs, frequency translators, and network monitors.

4.3 BACKBONE CABLE PLANT

A backbone cable plant connects the four subnetwork hubs. Either fiber optic cable or dual broadband coaxial cable may be used to connect the hubs. Figure 4-8 shows the selected hub locations for

Figure 4-8. Subnetwork Hubs and Backbone Cable Location

our model base. The hub within the ISS/ADPS has been designated as prime, and the hub within the MA has been designated as backup. The solid line between pairs of hubs shows a possible cable route for the backbone. Only the outer ring is required if a fiber optic cable (four-fiber cable) is installed. If a dual coaxial cable is installed, an additional cable pair is required between the prime and backup hubs. The location of these cables is shown by a dashed line. These additional cables are needed in a dual coaxial cable plant if a reconfiguration capability is to be achieved. This follows from the reconfigurable headend design described in section 5.

4.3.1 Fiber Optic Backbone

The backbone distances between hub pairs is given in table 4-10.

Table 4-10. Backbone Segment Lengths

Segment	Distance
MA to Wing CMD	918 m
Wing CMD to ADPS	513 m
ADPS to Supply	1764 m
Supply to MA	864 m
Total	4059 m

All interhub backbone segments are under 2 km in length, for which there is sufficient link margin without repeaters. The principal cost of the fiber optic backbone is for fiber optic cable and trenching. The entire medium between hubs is passive. It is assumed that backbone cable is identical to that used for the subnetwork feeders. Two fibers are of the large core graded index fiber type (85/125 or 62/125), and two are of the single-mode fiber type. The two graded index fibers are terminated while the two single-mode fibers are provided for future systems capacity. (The cable between hubs may contain more fibers if the same hub locations correspond to distributed voice PBXs and control network centers. This would decrease the prorated cost of cable for the data network.) At the hub, the fibers are terminated and jumpers provide connection to the hub electronics.

An estimate of costs for the fiber optic backbone is given in table 4-11.

Table 4-11. Fiber Optic Backbone Costs

Component	Number Required	Unit Cost	Total
Hub Terminations			
Panel	4 X 1	$41.00	$ 164
FO Jumpers	4 X 4	74.00	1,184
Couplers	4 X 4	10.25	164
Backbone			
Cable (4 fiber)	4,059 m	3.75	15,221
Connectors	4 X 4	14.25	228
Labor	4 h	50/h	200
Trenching	4,059 m	4.00	16,236
	Total Cost		$33,397

4.3.2 Coaxial Cable Backbone

The coaxial cable backbone requires the installation of an additional dual cable between the prime and backup hubs. In addition, the backbone signals will require amplification (trunk amplifier) upon leaving and entering the hub. Some of the links are sufficiently long that one or more trunk amplifiers are required to make up for cable losses. Table 4-12 provides distances of the five required segments and the number of amplifiers needed (excluding those at the hubs) on each segment. The number of amplifiers is based on the use of 3/4-inch cable. An amplifier is required for each 554 meters of cable length.

A total of 14 trunk amplifiers (7 inbound and 7 outbound) are required at 7 pedestal locations between hubs. An additional 20 amplifiers are required as outbound and inbound drivers at the hubs. Each amplifier will have associated with it two multiport taps for injecting and receiving test signals.

An estimate of costs for the dual coaxial cable backbone is given in table 4-13.

Table 4-12. Coaxial Cable Backbone Segment Lengths

Segment	Distance	Number of Amplifiers
MA to Wing CMD	918 m	2 X 1
Wing CMD to ADPS	513 m	0
ADPS to Supply	1764 m	2 X 3
Supply to MA	864 m	2 X 1
ADPS to Supply	1269 m	2 X 2
Total	5328 m	14

Table 4-13. Dual Coaxial Cable Backbone Costs

Component	Number Required	Unit Cost	Total
Cable (0.75)	10,656 m	$2.14/m	$22,804
Amplifier (Trunk)	34	952.00	32,368
Multiport Taps	68	20.00	1,360
Connectors	204	5.50	1,122
Trenching	5.328 km	4000/km	21,312
Pedestal and Access Panel	7	1500.00	10,500
Cable Connectorization	50 h	50.00/h	2,500
	Total		$91,966

The cost of the coaxial cable backbone is almost three times as great as that of the fiber optic backbone. This occurs because the fiber optic plant is completely passive between hubs while the coaxial cable plant requires amplifiers and the physical and electrical access to these amplifiers. Furthermore, the need for amplifiers along the way makes the coaxial cable backbone far more susceptible to sabotage at points where the cable leaves the trench to enter an above-ground access panel for amplification.

4.4 COMPARATIVE CABLE PLANT COSTS

Fiber optic and coaxial cable plants were designed for a typical subnetwork and the interconnecting backbone. The comparative costs for the two cabling options are given in table 4-14.

Table 4-14. Comparative Basewide Cable Plant Costs

Component	Number Required	Unit Cost	Total
FO Feeder	4	$43,344	$173,376
FO Backbone	1	33,397	33,397
	Total (Basewide FO Plant)		$206,773
Coaxial Cable Feeder	4	$35,341	$141,364
Coaxial Cable Backbone	1	91,966	91,966
Total (Basewide Coaxial Cable Plant)			$233,330

The two cable plants are of comparable cost. It has long been assumed that a fiber optic plant costs more than a comparable dual coaxial cable plant. That is clearly not the case. As previously stated, the fiber optic plant does not include termination components (connectors, couplers, and jumpers) for the single-mode fiber. At present, there are no requirements for the capacity offered by single-mode fiber. Within the 3- to 5-year time frame, when this medium is first required, single-mode termination component costs should be comparable to the present cost of multimode components. Under this assumption, the added cost for terminating the single-mode fiber within the cable will be approximately $25,000.

The cost listed in table 4-14 includes the expense for materials, labor of connectorization, and trenching. Other costs common to both cable plants have not been estimated for inclusion in the cost figures. No provision has been made for the labor of installing termination panels in the wiring closets, drilling through building foundations for entry, engineering labor for design and layout of the cable plant, and for profit. These costs are comparable for any new installation including twisted pair.

Now that alternative cable plants have been developed, it is necessary to show at least one approach to using each cable plant. In section 5 one of many possible approaches to using both the fiber optic cable plant and coaxial cable plant to form a useful base data network will be developed.

SECTION 5

NETWORK OPTIONS

The two cable plants described allow a variety of local area network options. Table 5-1 lists five representative approaches to providing data communications on a flying mission base. The fiber optic cable plant can implement networks based on a centralized packet controller (CPC), a star shaped token ring (SSTR), or other networks. The emphasis in this section will be on the CPC because it is well developed. In addition, representative equipment of this type already has a network monitoring function with a high degree of fault isolation and reconfiguration capability.

The dual cable plant may be used for contention bus (CB), token passing bus (TPB), or other networks. This section emphasizes the CB because of its wide use. Furthermore, approaches to network monitoring for location and isolation of failed subnetwork portions for this type of network are being developed at MITRE.

The digital PBX, unlike other local area network (LAN) equipment that allocates bandwidth in response to demand, provides a dedicated channel of medium data rate (56 or 64 kb/s). Where spare twisted copper pairs are available to buildings containing few terminals (three or less), its use permits a cost effective networking approach. Buildings outside the four base subnetworks may best be served by the base switch.

The base data communication requirement study has quantified the number of terminals or microcomputers in each of the functional areas on a flying mission base. Certain areas will also require minicomputers as part of a local subnetwork. To simplify the discussion herein and extend our base model, assume that functional areas within each of the four subnetworks previously defined will require one of three levels of service described below. The levels of service will be referred to as full, personal computer (or microcomputer) network (PCN), and terminal. The subnetwork model requires that 3 of the 13 functional areas in a subnetwork have full service with 1 minicomputer, 5 microcomputers, and 6 terminals. Where PCs are colocated, assume that a need exists for local communications among the PCs over a PCN. The terminals are assumed to be adequately served by an RS-232 port on the subnetwork.

Table 5-1. Local Area Network Options

Centralized Packet Control	CPC	
	Topology:	A hierarchical star with centralized short bus
	Access:	Non-destructive contention with round robin priority
	Examples:	Information Systems Network, ISN™ (ATTIS)
Star Shaped Token Ring	SSTR	
	Topology:	Star shaped ring feeder, dual reversible ring backbone
	Access:	Token with/without priority
	Examples:	proNET™, Future 802.4 Standard
Contention Bus	CB	
	Topology:	Rooted tree with dual broadband bus distribution
	Access:	Contention over distributed bus
	Examples:	Net/One™ (UB), LocalNet 40 (Sytek)
Token Passing Bus	TPB	
	Topology:	Rooted tree with dual broadband bus
	Access:	Token passing combined with contention slots
	Examples:	UniLAN™ (Applitek)
Digital PBX	DP	
	Topology:	Star
	Access:	Fixed (TDM)
	Examples:	SL-100 (Northern Telecom)

Below the full service level is the PCN level. Six of the thirteen functional areas in a subnetwork will have a PCN level of service with four microcomputers and six terminals. Finally, 4 of the 13 functional areas will be adequately served by terminal level service in which 4 terminals are in each functional area. This model, which is summarized in table 5-2, allows alternate network approaches and options within each approach to be compared.

Table 5-2. Service Levels of Typical Subnetwork

Service Type	Data Processing Equipment	Network Requirements
Full 3/subnet	1 minicomputer 5 microcomputer 6 terminals	Specific PCN RS-232
PCN 6/subnet	4 microcomputer 6 terminals	PCN RS-232
Terminal 4/subnet	4 terminals	RS-232

5.1 CENTRALIZED PACKET CONTROLLER FOR FIBER OPTIC CABLE PLANT

The centralized packet controller (CPC) is the hub element in a packet switched network. It provides the required routing of data packets from sender to receiver over a virtual circuit established at call setup time. The CPC, unlike a PBX, uses contention access among input devices. This allows a dynamic allocation of network bandwidth in response to data transfer requirements.

An example of the CPC technology, also referred to as a "virtual circuit switch," has been developed by AT&T.[5] It is marketed in two forms: Datakit for large telecommunication networks (AT&T Communications) and Information Systems Network (ISN) for campus-like environments (AT&T Information Systems). The latter is most appropriate to the base environment and will be used in the discussion as a concrete example of a network based on modern CPC technology. A brief description of ISN hardware and operation follows:

The topology of ISN is the hierarchical star with contention on a short bus. The network is formed by the following elements:

a. A packet controller acts as a switch and management center. All messages between sending and receiving devices contend on a short bus in the packet controller. A packet controller is located at each of the four hubs on our model base.

b. Concentrators are linked to the packet controller by means of fiber optic subnetwork feeders. In the version of an ISN network that is described first, a concentrator is located in the wiring closet of each building in the subnetwork.

c. Interface modules plug into either the packet controller or remote concentrator. They provide the interface between the ISN switch and user and network attachments that include fiber trunks, asynchronous and synchronous terminals, UNIBUS hosts, X.25, Ethernet™, and StarLAN. (StarLAN is a CSMA/CD network operating at a 1-Mb/s data rate over copper wire pairs. StarLAN is described in appendix A.) The second version of an ISN network, to be described herein, also implements StarLAN over the fiber optic subnetwork feeders. This eliminates the need for locating concentrators at each building.

The packet controller consists of two to four shelves that are rack-mounted in a cabinet. A two-shelf version is shown in figure 5-1. The data control unit (DCU), on the first shelf of the packet controller, contains the modules that perform call processing, switching, administration, and maintenance. The information interface carrier (IIC), on the second shelf, contains the modules that provide an interface between user devices and the packet controller. Characteristics and functions of the modules of the DCU and IIC are given in appendix B. The packet controller also provides battery backup that supports DCU operations for 10 minutes in the event of a power failure.

A system control console connects directly to the DCU via a dedicated port. The system manager can initialize the system, call for reports on system health or data traffic patterns, and issue commands to administer and maintain the network. One system console can serve the four packet controllers on base. For redundancy, a system console should be collocated with the packet controller at each of the hubs.

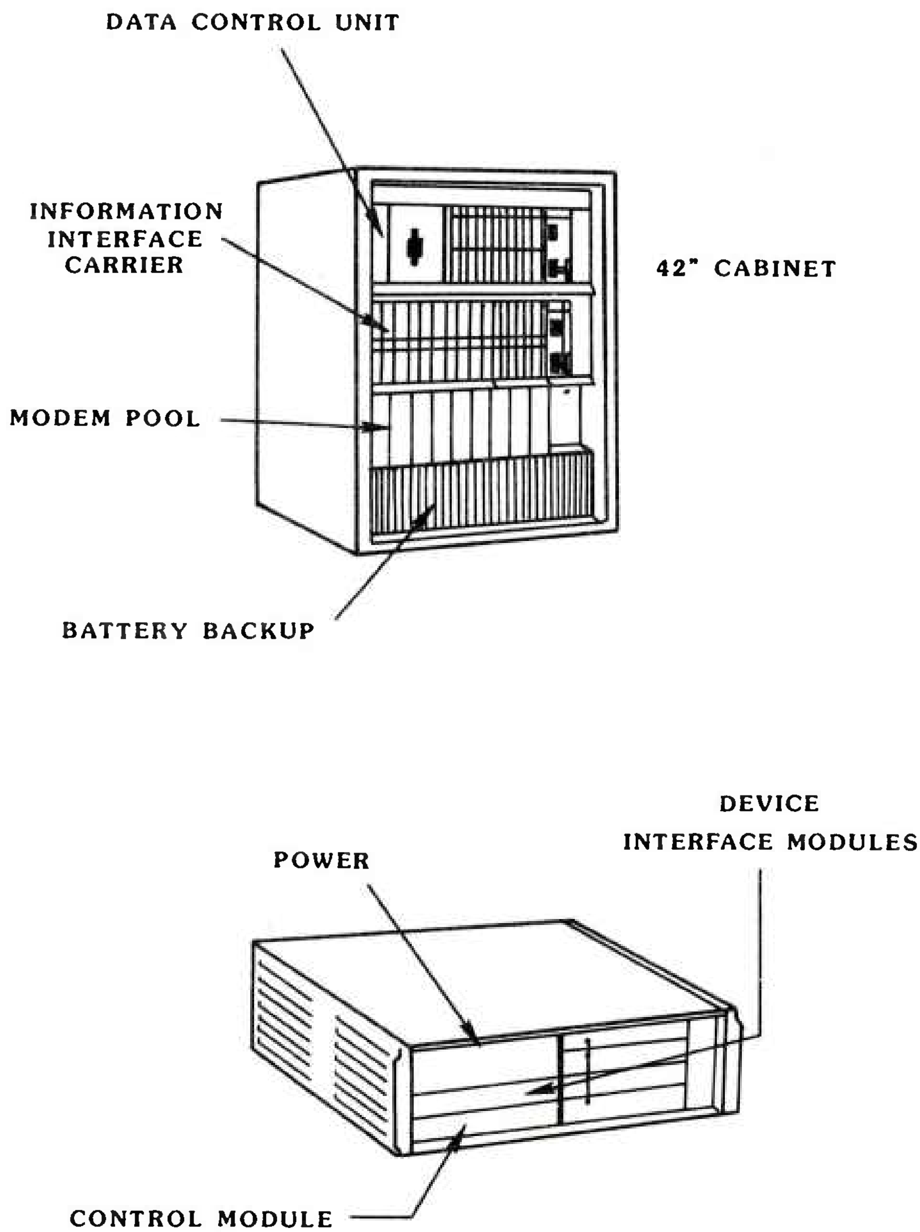


Figure 5-1. ISN Packet Controller and Concentrator

The concentrator multiplexes message packets from interface modules for transmission over optical fiber to the packet controller. The concentrator contains slots for up to five interface modules. The same interface modules listed in table B-2 of appendix B may be used in either the concentrator or packet controller.

5.1.1 Principle of Operation

Data messages within the ISN network are sent in the form of short fixed length packets (180 bits). The packets from several messages are interleaved into a sequence of time slots on the CPC backplane transmission bus, taking advantage of gaps in one device's transaction to transmit data from another device. The packets that are interspersed on the packet controller short bus carry an address that directs them to a final destination where they are reassembled into whole messages. The ISN packet controller can support up to 1200 simultaneous full-duplex virtual circuits by these means.

The ISN packets have low overhead.[5] On transmission, a module provides only a source address. The packet controller converts the source address to a destination address so that only the intended receiver module intercepts the message. The address is converted by the DCU. The DCU establishes a virtual circuit when its call processor writes an entry in the memory of the switch indicating that all packets arriving from a given sender (source address) are to be routed to a particular destination (destination address). The routing may include transmission through one or several packet controllers. Packet controllers are connected through fiber optic modules. When a session is completed, the call processor disconnects the virtual circuits by removing the entry from switch memory. For the duration of the session, the switch replaces each packet's current source address with the appropriate next destination address. The last packet controller through which the message passes replaces the address with the final destination address of the interface module for which the packet is intended.

Access to the short bus is granted by means of non-destructive contention. The switching process involves three short buses on the backplane of the packet controller, as shown in figure 5-2. The transmit bus carries packets from sending modules to the switch. The receive bus carries packets away from the switch to modules for transmission to attached data devices. The order of access to the transmission bus is determined on the contention bus. The manner in which contention is resolved is described below.

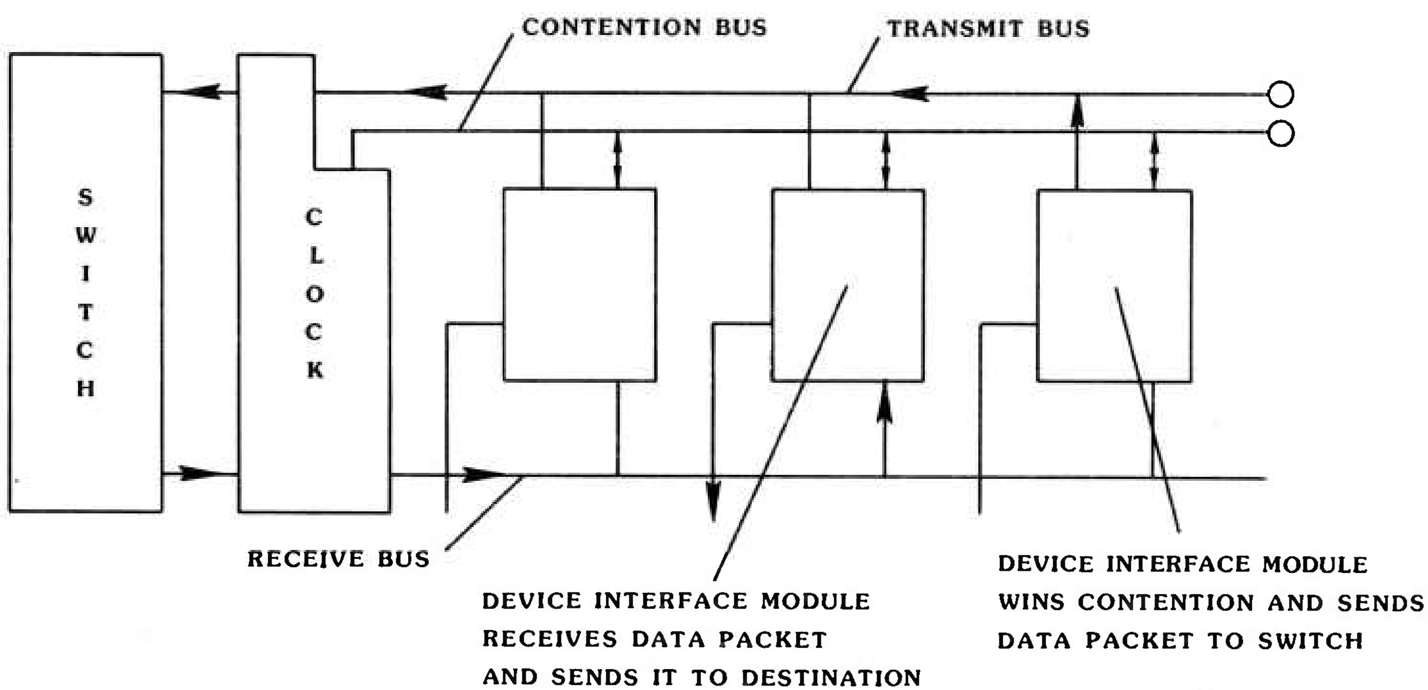


Figure 5-2. ISN Backbone Bus Design

Since the buses are short, with propagation delay shorter than a single bit time, contention can be resolved without destructive collisions. All modules having packets of data ready to send compete for access during the time slot preceding the next transmission slot. Each module transmits its own contention code onto the contention bus while comparing the status of the bus bit by bit. The bus status is the logical OR of all input bits. A module that transmits a zero and notes a bus status of one ceases to transmit and defers to the module with the higher contention code. In an orderly fashion, access is gained by the module with the highest binary contention code, and that module packet is placed on the transmission bus for switching during the next time slot. Losing modules have a better chance to win in subsequent time slots, because a "round robin" algorithm raises their codes to a higher value than those of packets arriving later.

5.1.2 Backbone for Packet Controller Hubs

A backbone network having desirable survivability features is easily implemented with CPC hubs. The only additional hardware required beyond the packet controller consists of the fiber optic transceiver modules for connection to the backbone cable plant. During system initialization, the mapping of the network is loaded into the memory of each packet controller.

A simple alternate routing algorithm works in the following manner. When a microcomputer that is a member of subnetwork A wishes to establish a session with a minicomputer within subnetwork D, the preferred virtual circuit is over the single trunk from A to D as shown in figure 5-3. If the A to D trunk is inoperative or overloaded, the packet controller will establish a virtual circuit by routing packets through B and C to D. This minimal alternate routing capability inherent to CPC assures that an impairment to a single hub or trunk does not hinder the flow of data traffic over the balance of the base network.

If warranted, additional backbone trunks may be incorporated from A to C and from B to D to provide an even higher degree of backbone survivability. This option will require the development of additional routing software for the packet controller.

Table 5-3 provides a cost estimate of the hub electronics that can be attributed to the backbone. For the purpose of this exercise, assume that half the cost of each of the four packet controllers is allocated to the backbone and half is allocated to the subnetwork feeder network portion described in following sections.

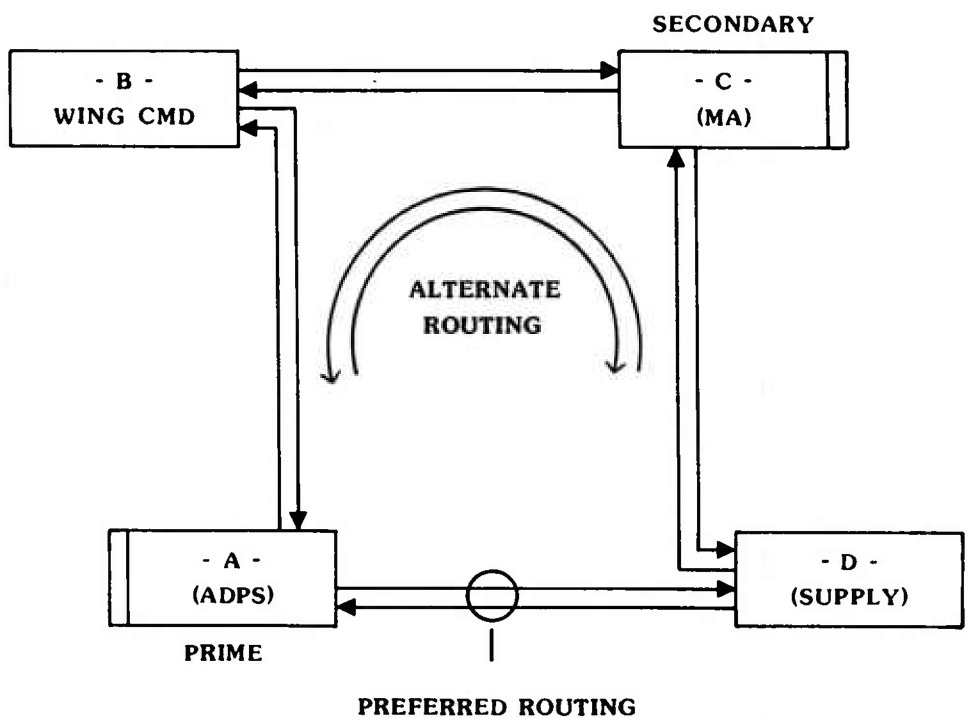


Figure 5-3. Backbone for Packet Controller Hubs

Table 5-3. ISN Backbone Costs

Components	Unit Cost	Quantity	Cost
Packet Controller*	$23,170	0.5 X 4	$46,340
System Control Console	1,117	0.5 X 4	2,234
Fiber Trunk Module	2,150	8	17,200
		Total	$65,774

*Includes DCU and single IIC shelf plus battery backup for DCU operations for 10 minutes in the event of a power failure.

5.1.3 Subnetworks Using Concentrators

The four subnetworks that each originate from an ISN packet controller may either make use of remote concentrators or rely on an extended StarLAN feeder. The use of remote concentrators will be described in this section. This approach provides a high data rate capability to each building so that minicomputers can be located freely and still have the capability of exchanging files at megabit rates. This approach lacks some of the survivability features provided by a network making more extensive use of StarLAN. Communication over StarLAN can continue even if the CPC is disabled. A description of StarLAN topology, access protocol, and equipment is provided in appendix A.

The subnetwork configuration for a building requiring the "full" level of service is shown in figure 5-4. The packet controller is at the hub. Two fiber trunk modules service the backbone trunk connections. Thirteen other fiber trunk modules serve the feeders to the 13 functional areas of the subnetwork. Within the building wiring closet the feeder is terminated with a concentrator, which contains a fiber trunk interface. The concentrator accepts up to five interface modules and multiplexes their signals together.

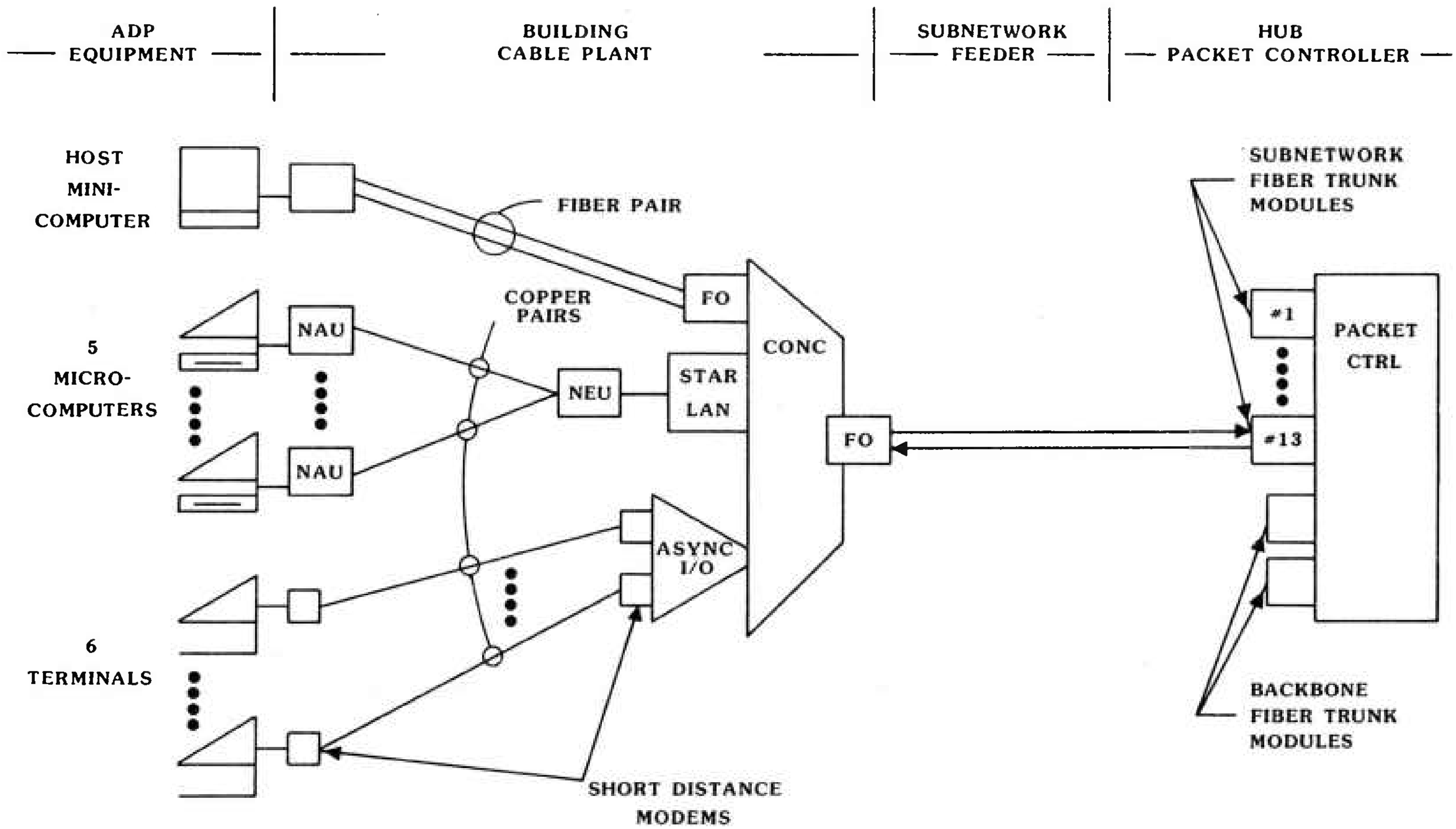


Figure 5-4. Subnetwork Using Concentrators (Full Service)

The concentrator does not perform the switching function (convert source to destination address). Inbound and outbound messages between the minicomputer and terminals need to pass through the concentrator before and after being switched by the packet controller. Thus, communications can only be achieved when the subnetwork feeder cable and packet controller are operational.

Three kinds of modules are required at the concentrator for the full service level. A special fiber optic point-to-point link provides an interface between the KMC-11 front-end processor of a DEC UNIBUS minicomputer and the concentrator. This approach allows minicomputers to execute file transfers at megabit rates over this high speed link.

A StarLAN module provides an interface between the ISN network and a local PC network used for intrabuilding communications among microcomputers. The microcomputers are connected with copper pair wire to the building wiring closet. Signal distortion limits the maximum signaling distance over twisted pair to 800 feet. StarLAN is a baseband CSMA/CD network with a 1-Mb/s data rate. The network access unit (NAU) card plugs directly into a spare slot of a microcomputer. A network extender unit (NEU) allows the copper pair from as many as 11 NAUs to be joined and permits attachment to the StarLAN module. A property of the StarLAN network is that communication between members of the network is possible even when the concentrator, subnetwork feeder, and packet controller are disabled. This degree of local network survivability is highly desirable for small mission essential subnetworks.

Finally, an asynchronous terminal interface module provides an interface between the ISN network and as many as eight RS-232 ports. If the terminals are some distance (greater than 50 feet) from the concentrator, the signals must be conditioned with short distance modems (converted to a signaling waveform such as the RS-422) to permit transmission over distances up to 4000 feet.

Figure 5-4 provided the subnetwork configuration for the previously defined full level of service. Lower levels of service are achieved by deleting portions of the figure. The PCN level eliminates the minicomputer connection and one NAU of the StarLAN. The terminal level eliminates the minicomputer connection, all StarLAN connections and reduces the required number of short distance modems.

Based on our model subnetwork (three full service, six PCN, and four terminal configuration) we can estimate the cost of a typical ISN subnetwork using concentrators. Component costs are provided in table 5-4. Half the cost of the packet controller will be allocated to the subnetwork portion. Since a total of 13 functional areas are

Table 5-4. ISN Subnetwork Costs (With Concentrators)

		Service Level					
		Full		PCN		Terminal	
Component	Unit Cost	Quant.	Cost	Quant.	Cost	Quant.	Cost
KMC-11	$2,580	1	$2,580	-	$0	-	$0
Host I/O	3,310	1	3,310	-	0	-	0
NAU-PC	595	5	2,975	4	2,380	-	0
NEU	575	1	575	1	575	-	0
Starlan Module	2,800	1	2,800	-	2,800	-	0
Async Module	1,710	1	1,710	1	1,710	1	1,710
Short Dist Modem	100	12	1,200	12	1,200	8	800
Fiber Trunk Module	2,150	2	4,300	1	2,150	1	2,150
Concentrator	5,000	1	5,000	1	5,000	1	5,000
Packet Controller	23,170	1/26	891	1/26	891	1/26	891
System Console	1,117	1/26	43	1/26	43	1/26	43
	Totals		$25,384		16,749		$10,594

Typical Subnetwork

Service Level	Quantity	Cost
Full	3	$ 76,152
PCN	6	100,494
Terminal	4	42,376
Total/Subnetwork		$ 219,022

being fed from the packet controller, 1/26 of the cost is assigned to each subnetwork endpoint. Following a description of an ISN implementation that uses a StarLAN extension to the hub, the two approaches will be compared in terms of performance and cost.

5.1.4 Subnetworks Using StarLAN

Subnetwork survivability is enhanced when the StarLAN network is extended back to the hub where the ISN packet controller is located. The penalty for this approach is that file transfers between minicomputers are limited by the CSMA/CD protocol and the limited burst signaling rate of 1 Mb/s.

The subnetwork configuration for a building requiring the "full" level of service is shown in figure 5-5. The packet controller is at the hub. As before, two fiber trunk modules service the backbone trunk connections. A number of StarLAN modules serve as connections to StarLAN PC networks within the subnetwork.

Within a building all ADP equipment is connected via StarLAN using existing copper pair wiring. NAUs are used to interface minicomputers and microprocessors to StarLAN. Network interface units (NIUs) are used to interface pairs of terminals to StarLAN. The NEU is located in the building wiring closet. It allows the copper pair from the six NAUs and the three NIUs to be combined into a common StarLAN.

Since waveform distortion occurs over copper pair, a repeater must be provided to regenerate and reclock StarLAN signals. To permit transmission over distances greater than 800 feet between repeaters, fiber optic transceivers are used to extend StarLAN over the feeders to the subnetwork hub. (The repeater and fiber optic transceivers for StarLAN are not yet commercially manufactured, and therefore their costs are estimated.) At the hub, each feeder could be connected to a StarLAN module at the ISN packet controller. An alternative connection approach assumed in this model is to first combine StarLAN feeders from functional organizations that have extensive communications with one another by means of an NEU. The latter approach offers an additional degree of survivability. Even if the packet controller were disabled, all members on a StarLAN would be capable of unimpeded communications among themselves. This approach also offers some cost benefits since fewer StarLAN modules are required.

Figure 5-5 provides the subnetwork configuration in which pairs of Starlan feeders are combined through NEUs before connection through StarLAN modules to the ISN packet controller. A cost estimate for this type of network structure is provided in table 5-5.

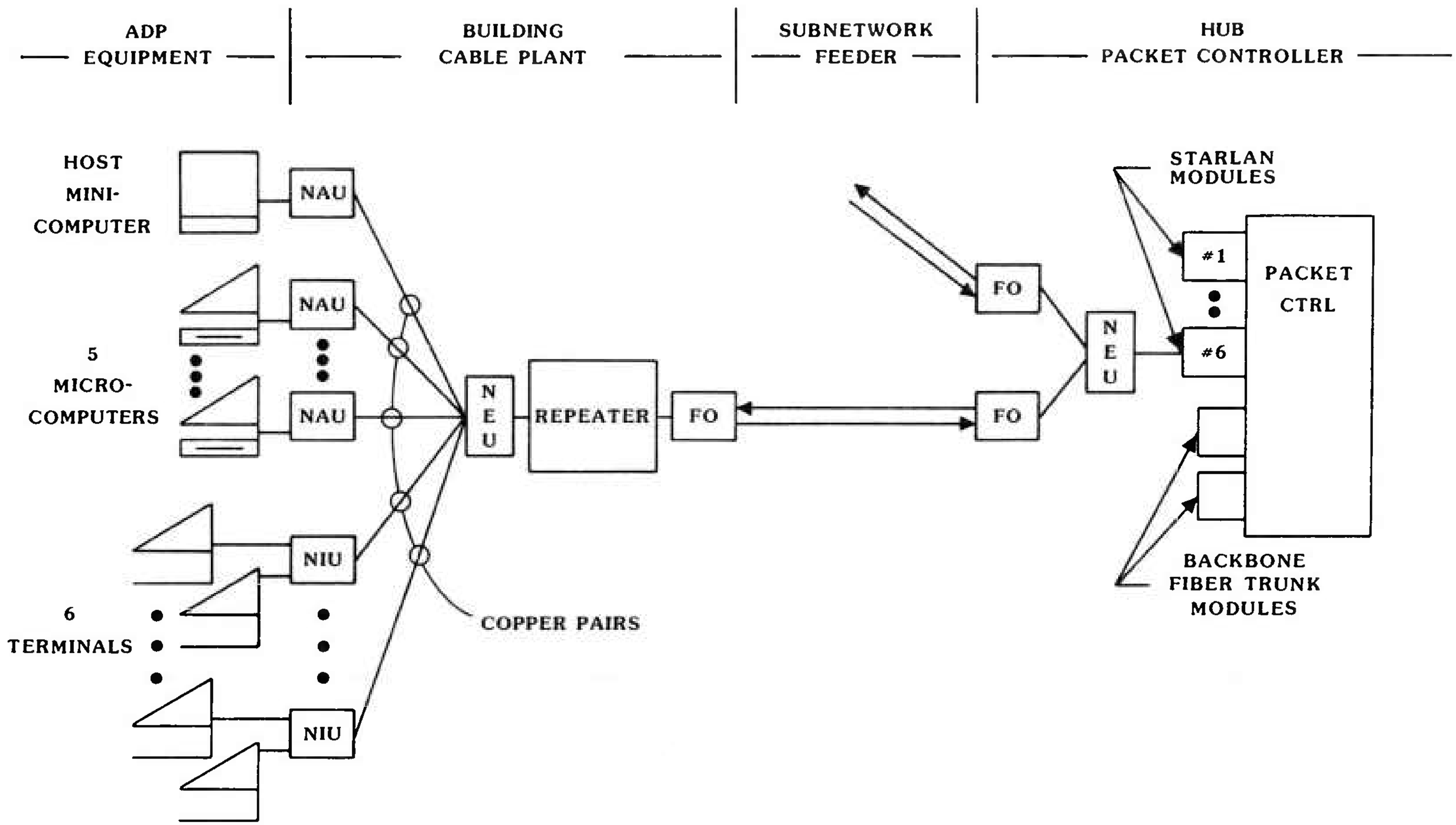


Figure 5-5. Subnetwork Using StarLAN Extension (Full Service)

Table 5-5. ISN Subnetwork Costs (StarLAN Extension)

Component	Unit Cost	Full Quant.	Full Cost	PCN Quant.	PCN Cost	Terminal Quant.	Terminal Cost
NAU-Mini	$895	1	$895	-	$0	-	$0
NAU-PC	595	5	2,975	4	2,380	-	0
NIU	750	3	2,250	3	2,250	2	1,500
NEU	575	1.5	863	1.5	863	1.5	863
Repeater	1,200*	1	1,200	1	1,200	1	1,200
Fiber Trunk Unit	2,150*	2	4,300	2	4,300	2	4,300
Starlan Module	2,800	0.5	1,400	0.5	1,400	0.5	1,400
Packet Controller	23,170	1/26	891	1/26	891	1/26	891
System Console	1,117	1/26	43	1/26	43	1/26	43
Totals			$14,817		$13,327		$10,197

Typical Subnetwork	Service Level	Quantity	Cost
	Full	3	$44,451
	PCN	6	79,962
	Terminal	4	40,788
Total/Subnetwork			$165,201

* Estimated values

5.1.5 Summary of CPC Network Features and Cost

The ISN centralized packet controller offers desirable network features as summarized in table 5-6. Two approaches to implementing the ISN network were described. Extensive use of StarLAN within the subnetwork enhances survivability among functional areas on the same StarLAN segment. This approach limits throughput on file transfers between minicomputers or between minicomputers and microcomputers. The base visits have not indicated that there is a current need for many file transfers of this type. If further investigation shows that certain functional areas require higher throughput than can be accommodated over a StarLAN connection, then concentrators should be located in those specific buildings.

For the purpose of establishing a cost for the base network using ISN and optical fiber, assume that 2/3 of the functional areas are served by StarLAN based networks while 1/3 of the functional areas require concentrators. The two approaches can be mixed within one subnetwork. Table 5-7 summarizes the ISN network and cable plant costs based on this mixture.

5.2 CONTENTION BUS INTERFACE UNITS FOR COAXIAL CABLE PLANT

The data network described in this section uses only one of the many available 6-MHz analog channels on the inbound and outbound broadband coaxial cable of the network. The coaxial cable may additionally be used for multiple data channels, each serving a limited community of users, or it may be used for analog video distribution. These applications may be developed in response to future requirements (with the addition of other headend equipment).

The contention bus network was developed to allow a large number (N) of data processing equipment to be fully connected without the need for $N \bullet (N-1)$ point-to-point connections. One of its principal attributes is that every device attached to the network can in principle share information with every other device. This is an especially important attribute in the command and control environment where data are entered at many operator positions and these data must be available to every other operator at his position. This type of broadcast traffic is usually not required in the office automation environment. This permits use of virtual circuit service.

The flying mission base in our model extends over several kilometers, and not all cables or headends can be fully secured from sabotage. Since there is a requirement to preserve mission essential traffic in the face of both physical and electronic sabotage, it is necessary to design a network that is survivable. In the case of ISN, the use of

Table 5-6. ISN Features

Performance

Data Rate	8.64 Mb/s at each subnetwork packet controller
Loading	1220 virtual circuits at a packet controller
Access	Collision-free perfect scheduling with fair "round robin" access

Security Features

Data packets only to addressed subnetwork feeder
No emanations from glass fiber feeder or backbone

Survivability

Repeaterless feeder and backbone; entirely buried cable plant
Automatic monitoring of ISN modules with failure alarm
Alternate backbone routing around cable or hub failures
Battery backup for short term power failures

Network Management

Equipment configuration, faulty module location
Call setup failures, simultaneous connections
Automatic alarm generation
Self-health check of packet controller

Interfaces

X.25, System 85 PBX, Ethernet™

With Concentrators

Full data rate available to remote host minicomputer (8.64 Mb/s)

With StarLAN

Survivable autonomous PC networks

Table 5-7. Basewide ISN Network Costs

Component	Unit Cost	Source Table	Quantity	Total
Feeder Subnet (StarLAN)	$165,201	(5-5)	(2/3) X 4	$440,536
Feeder Subnet (Concentrator)	219,022	(5-4)	(1/3 X 4)	292,033
Backbone Electronics	65,774	(5-3)	1	65,774
FO Cable	206,773	(4-13)	1	206,773
		Network Total		$1,005,116

multiple packet controllers meets this requirement. Switching and rerouting around failed hubs or backbone links is inherent in this equipment. A broadband cable plant also requires multiple headends for survivability. To provide the full connectivity of the contention network, only one headend is operative at a time. Sensors determine when a failure has occurred and respond accordingly.

5.2.1 Principle of Operation

Medium access control to the bus network is decentralized. Each BIU having a data packet ready for transmission first listens for carrier presence. If carrier is detected, transmission is delayed. If no carrier is present, transmission is begun immediately. The transmitted signal is an RF carrier (in the prescribed 6-MHz inbound frequency band data channel) modulated with the bit pattern of the data packet. This packet travels inbound to the headend where it is translated in frequency to the data channel outbound frequency band. If no other BIU has simultaneously attempted a transmission, the BIU will see an uncorrupted replica of the signal it transmitted.

If the return signal is corrupted, indicating that a collision has occurred, the BIU ceases to transmit and waits a random time before attempting a retransmission.

An increasing number of companies offer LAN products that implement the CSMA/CD access protocol over a broadband coaxial cable transmission plant. These products offer serial and parallel interfaces that accommodate terminals and a variety of microcomputers and minicomputers. The base environment also requires a network management capability offering maximum flexibility for controlling access, monitoring traffic flow, identifying faults, and sending alarms. The bus interface units (BIUs) and network management console (NMC) of Ungermann-Bass represent state-of-the-art equipment and software appropriate to the base environment. The capabilities and prices of these products will be used in describing operation and cost of a base network using coaxial cable as its transmission medium.

The network is under the control of a network administrator having software capabilities that allow the BIUs to be set up with specific parameters that are automatically "down-line loaded" to each unit entering the network. The port parameter includes data characteristics (data bits, stop bits, parity), transmission rates, device specifications (special characteristics for backspace, word/line delete, upper and lower ASCCII symbols), and names to be used for connection service. The kind of service to be provided (virtual circuit or datagram) is also provided to each unit upon initialization. The degree of flexibility and control provided directly result from the use of a centralized NMC.

The network configuration software can be installed in an IBM PC-XT with 512 kilobytes of memory and a 10-megabyte Winchester disk. This is the minimum system configuration that is adequate for a subnetwork in a stand-alone mode. This minimum configuration does not provide the full range of capabilities needed by the network administrator when the backbone is operational. Those additional capabilities include a data link monitor that reports on the flow of traffic on the network. The reports include the number of network logins, password attempt failures, resource connections established or denied, virtual circuit terminations, volume of data transferred, length of virtual circuit connection time, BIU bootload requests, downloading or failure to download to the BIU, amount of network bandwidth used, BIU resets, and ports enabled and disabled. This type of administrative software is installed in a SUN workstation.

A SUN workstation allows additional troubleshooting by means of a network debugger. This software tool allows the network administrator to examine the RAM contents of every BIU and modify its contents to effect repairs. Remote command of restart, running of initialization diagnostics, and requests for a configuration download can be remotely commanded. In the area of control, validation server software is installed in the SUN workstation. The validation server is a mechanism that permits or denies users access to the network and its resources. The validation server guards the network and its resources from unauthorized use.

5.2.2 Fault Isolation in Subnetwork Feeder

The requirement to preserve mission essential traffic in the face of both physical and electronic threats mandates a feeder design formed into a tree topology rather than a linear bus topology. In this way failed BIUs or jammers can be rapidly located and isolated. This is done by means of an in-line "sniffer" device, which responds to the occurrence of a carrier of excessive duration on any branch of the tree. The triangles on figure 4-7 show appropriate locations for sniffers. Once jamming on an inbound cable is detected, that channel frequency on the inbound cable can be cut off from further transmission until a repair is affected.

A sniffer of the type required for the subnetwork feeder has been developed at MITRE. It is designed to fit into the same housing as an eight-port multitap. It is located on the inbound cable leg. Carrier detect circuits monitor carrier duration on one or two inbound data channels. If the duration of a carrier presence condition exceeds a lower threshold but not an upper threshold, a bit is set within the sniffer. At regular intervals, the sniffer is polled by a subnetwork controller. If conditions warrant, the subnetwork controller broadcasts a command to the sniffer over the outbound cable which results in the insertion of a notch filter into the inbound cable. The notch filter blocks transmission on the offending inbound data channel. When carrier duration exceeds the second threshold, the sniffer acts at its own initiative to insert the notch filter. The sniffer communicates its action to the subnetwork controller, which may command removal of the notch filter under operator control.

Both the sniffer and subnetwork controller are under development at MITRE. The sniffer contains a transmitter and receiver, carrier sense circuits, microcontroller and ROM chips, RF relays, and two notch filters. It has been estimated that such a device can be manufactured (including profit) at a cost of $500. The subnetwork feeder would require seven sniffers located as shown in figure 4-7. The subnetwork controller is also under development at MITRE. It is based on a single card microprocessor with a multibus I/O. The hardware, software, and packaging costs for production quantities are estimated at $5,000. One subnetwork controller is required at each of the four hubs. This local jammer location and isolation capability provide first-level survivability to a coaxial cable base data network.

5.2.3 Survivable Multiple Headend Backbone

A second level of base network survivability is provided by means of multiple headends. Only one headend can be operating at a time for a fully connected network. All inbound packets flow to a common headend over the backbone cable plants where the inbound data frequency band is translated to the outbound frequency band. For survivability, the headend function needs to be replicated around the network so that alternate headends are available. The active headend also needs to monitor backbone cable input from each subnetwork and cut off inputs that would impair the entire network.

Figure 5-6 shows a simplified block diagram of a backbone wiring plan with alternate headends. The prime headend, located at the subnetwork A hub, is shown at the top of the figure. Under normal conditions, the inbound cables with low frequency band inbound data traffic from subnetworks B, C, and D are connected over backbone cables through backbone switches to the prime headend. After frequency translation all data packets from all subnetworks are distributed locally on subnetwork A and over the backbone to subnetworks B, C, and D.

If the prime headend becomes inoperative due to its failure or the failure of backbone connections, the secondary headend takes over the headend function for the remaining portions of the network. Inbound data traffic from subnetworks B and C is connected over backbone cable through the backbone switches to the secondary headend. After frequency translation, all data packets are distributed locally on subnetwork D and over the backbone to subnetworks B and C.

Should a further impairment to the network occur so that the secondary headend becomes inoperative, each subnetwork (B and C) responds by forming a local headend and disconnecting itself from outbound traffic from both A and D.

A list of basic responses of the multiple headend backbone to various detected failures and recoveries is given in table 5-8. This list is only a beginning, but it shows that it is possible to provide a degree of survivability in coaxial cable networks approximately equivalent to that offered by ISN.

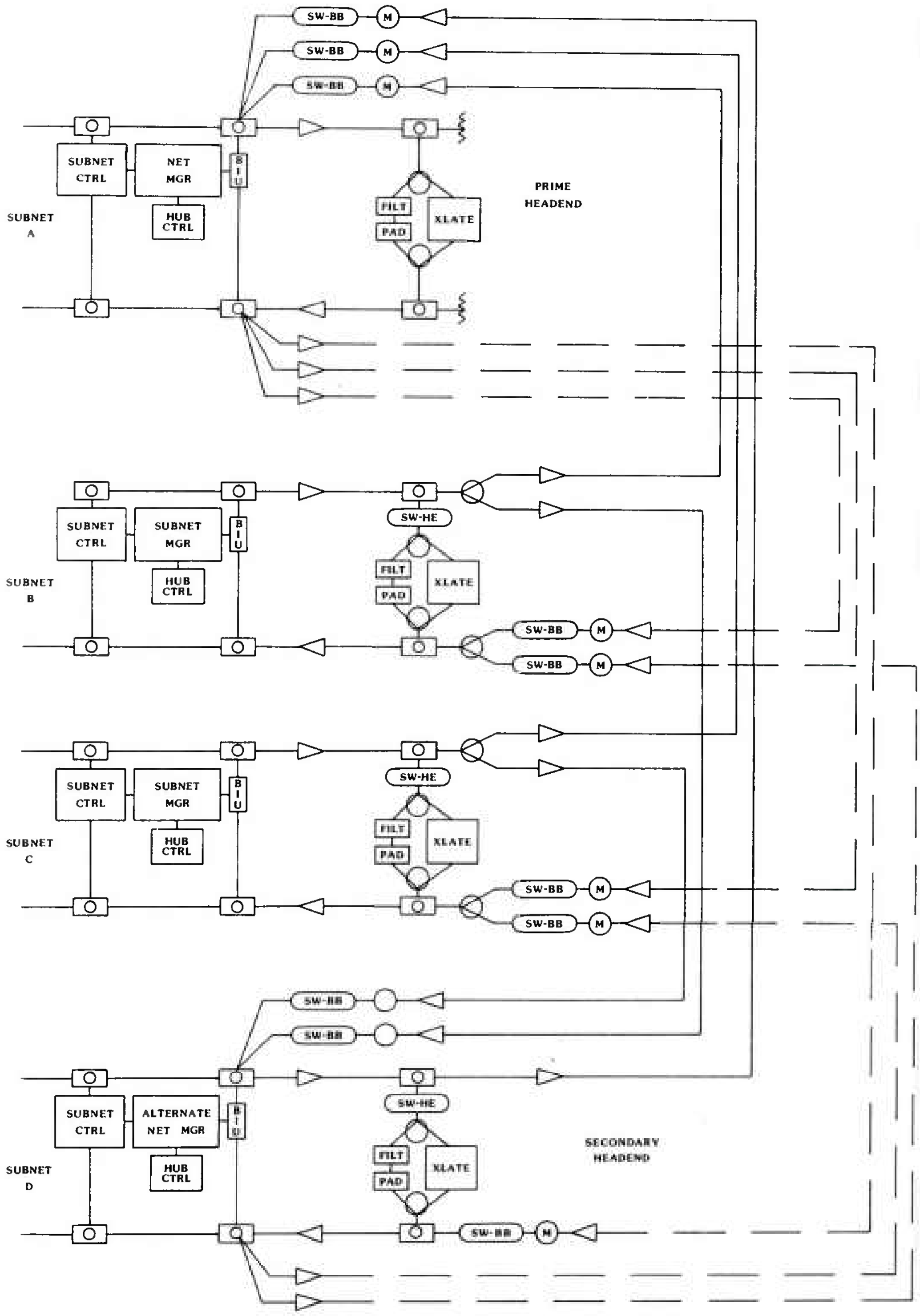


Figure 5-6. Coaxial Cable Backbone With Reconfigurable Headends

Table 5-8. Basic Backbone Reconfiguration Operations

Hub	Sensed Condition	Response
A (Prime)	Jamming from B (or C or D)	a) Open SW-BB from B b) Net Mgr A sends IRM to Subnet Mgr B
	Subnet Ctrl of B isolates jammer	a) Subnet Mgr B sends RJM to Net Mgr A b) Hub Ctrl A confirms corrected conditions and closes SW-BB from B
D (Secondary)	Jamming from A or no signal from A	a) Open SW-BB from A b) Close SW-HE in B (new headend) c) Close SW-BB from B and C d) Send CSHM to Subnet Mgr B and C (In response B and C transfer input (SW-BB) from A to B
B (or C) (Local)	Jamming from A or D or no signal	a) Send IRM to A or D b) Open SW-BB from A or D c) Close SW-HE in B (and/or C) (new local headend)

IRM	Information - Reconfiguration Message
RJM	Request - Join Network Message
CSHM	Command - Secondary Hub Message

The principal components of the prime and secondary headends are an NMC based on a SUN workstation, a redundant frequency translator with automatic switchover, a backbone monitor and switches under control of a hub single-board microprocessor, and the subnetwork single-board microprocessor previously described.

The two SUN workstation NMCs allow both the configuration software download function and administrative functions of network monitoring, network access control, and fault detection/reporting to be carried out from two locations within the base environment. Redundant frequency translators with automatic switchover are regularly incorporated into a headend to enhance reliability.

A single-board microprocessor, similar to those previously described as part of the subnet sniffer controller, is required to monitor backbone signal condition; control the backbone and headend RF switches; and issue and respond to information, request, and command messages. Ideally, the microprocessor provides a dedicated real-time function of sensing, controlling, issuing, and responding to messages. It should be compatible with the workstation interface bus to provide input to the network administrative functions. Such a device does not presently exist, but it will be assumed to have production costs equal to the subnetwork sniffer controller.

The principal components of the B and C local headends are an NMC based on an IBM-XT personal computer, a single-frequency translator, a backbone monitor and switches under control of a hub single-board microprocessor, and the subnetwork controller. These components are the minimum required for stand-alone subnetwork conditions. The estimated cost of the hub electronics for a broadband backbone is given in table 5-9. This table does not include the cost of components more properly identified with the subnetworks. Excluded are sniffers, subnetwork controllers, and the equivalent cost of a minimal NMC (IBM-XT). The estimated total cost of the components dedicated to a survivable multiple hub is $139,000.00. The bulk of this is the cost of two workstations.

5.2.4 Subnetworks Using BIU Attachments

Ideally, the dual cable broadband feeder shown in figure 4-6 was terminated in the wiring closet to make maximum use of existing copper pair wiring. This building wiring objective of locating all interface units in a wiring closet and using existing copper pair to DTE locations is only achieved for the terminals or other DTEs served by RS-232 ports. Presently, StarLAN-to-broadband coaxial cable BIUs are unavailable. This situation can be expected to change in the future. Consequently, a building requiring the "full level" of service will need to have a BIU for the host minicomputer, BIUs for each microcomputer, and one BIU to serve all terminals as shown in figure 5-7.

Table 5-9. Broadband Backbone Hub Electronics

Prime and Alternate Hubs (2 Required)

Component	Unit Cost	Quantity	Total
Network Manager (SUN Work Station)	$60,000	5/6*	$50,000
Backbone Switch and Monitor	500	3	1,500
Hub Controller	5,000	1	5,000
Frequency Translator (Redundant)	8,500	1	8,500
	Total per Hub		$65,000

Subnetwork Hubs: B or C (2 Required)

Component	Unit Cost	Quantity	Total
Network Server IBM/PC-AT	$10,000	0/1*	$ 0
Backbone Switch and Monitor	500	2	1,000
Frequency Translator	3,500	1	3,500
	Total per Hub		$4,500

Total Backbone Hub Electronics (4 hubs) $139,000

*$10,000 of each network manager or server has been assigned to subnetwork electronics.

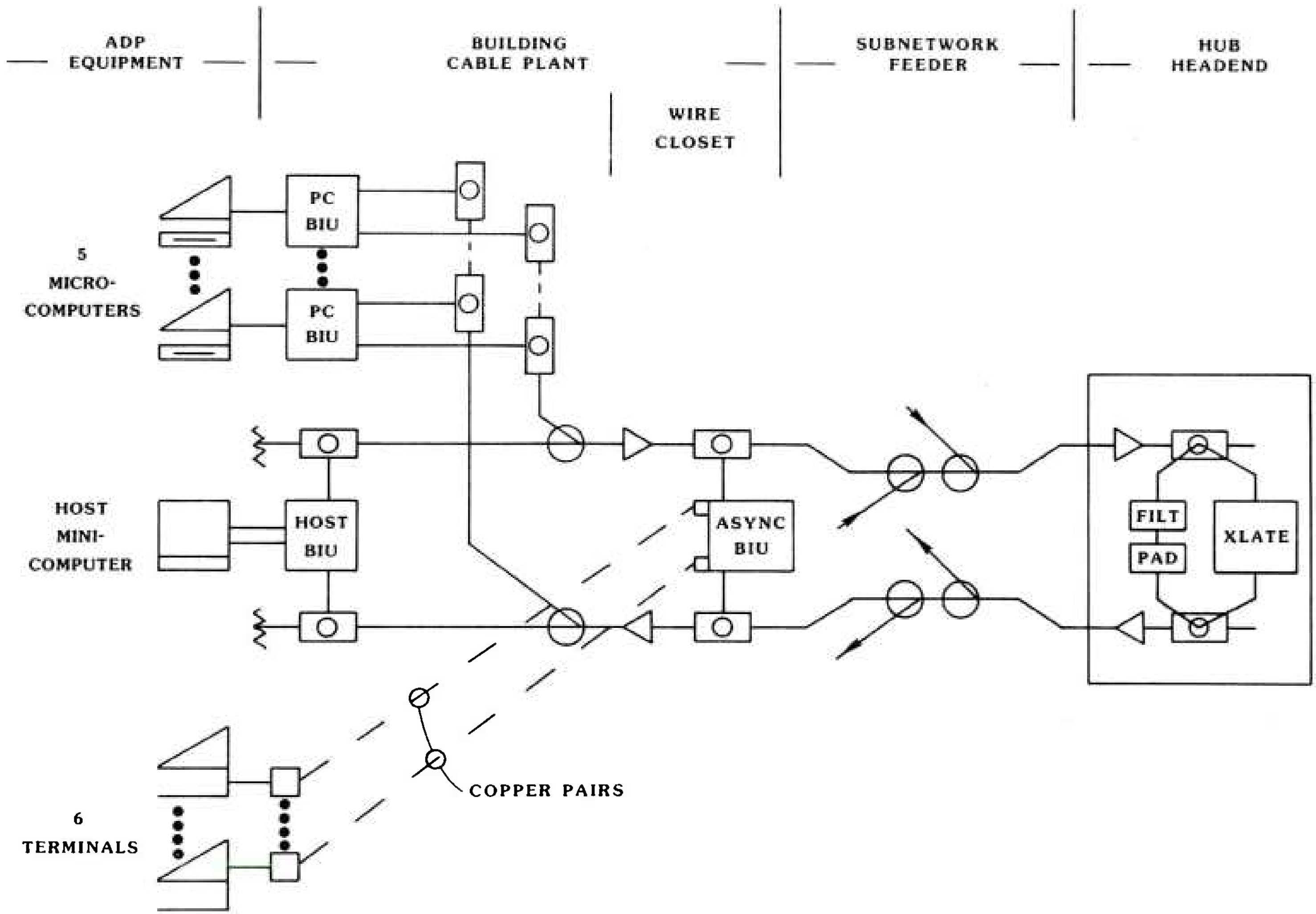


Figure 5-7. Subnetwork Using Direct Cable Attachment

Each microcomputer with high speed data transmission requirements has a plug-in interface card. The network side of the interface card must be connected to a dual cable broadband bus. Hence, the building wiring must be augmented with dual coaxial cable to at least the locale of the PCs and the host minicomputer (unless RS-232 connections are to be made to these devices). The coaxial cable plant extension will require line extender amplifiers (a minimum of one inbound and one outbound) plus cable with connectors and multitaps.

The estimated cost of a broadband subnetwork is given in table 5-10. Note that only the full and PCN service levels include coaxial cable and connectors (estimated at $300) and line extender amplifiers. The cost of subnetwork sniffer, subnetwork controller, and the basic level network management console is also added to subnetwork costs.

5.2.5 Summary of Broadband Contention Network Features and Costs

Under unstressed conditions, the broadband contention network that has been described herein uses one headend for the entire base. With this approach, the full and unimpeded connectivity needed in a command and control environment is obtained. Alternative designs may have features that merit consideration if a coaxial cable plant is favored for use on flying mission bases. One alternative network design is configured with an operating headend in each subnetwork. Bridges connected to the backbone support communications between subnetworks. Bridges may limit throughput to a level inadequate for the base environment. Also some of the redundancy features are lost because all four headends are always required.

A second alternative design uses frequency agile BIUs. Data packets destined for the local subnetwork are transmitted in one frequency band while packets for other subnetworks are broadcast on the base-wide frequency band. The local traffic is filtered and translated by the local headend. This type of BIU is probably more expensive since each BIU has to store the location of every other BIU. The network mapping is learned by trial and error or is downloaded by the network manager. Evaluation of these and other approaches to using a broadband coaxial cable plant is beyond the scope of this report.

The cable plant, which was designed with its sniffers and redundant headends, shows that it is possible to build a broadband coaxial cable plant with desired survivability features. Table 5-11 summarizes the costs for implementing such a broadband coaxial cable network.

Table 5-10. Broadband Subnetwork Costs

Component	Unit Cost	Full Quant.	Full Cost	PCN Quant.	PCN Cost	Terminal Quant.	Terminal Cost
DR-11	1,700	1	$1,700	-	$0	-	$0
Host BIU	$9,000	1	9,000	-	0	-	0
PC BIU	1,245	5	6,225	4	4980	-	0
Line Extender Amp	248	2	496	2	496	-	0
Multitaps	20	12	240	8	240	-	0
Cable and Connectors	300	1	300	1	300	-	0
Async BIU (180)	3,600	1	3,600	1	3,600	1	3,600
Short Dist Modem	100	12	1,200	12	1,200	8	800
Sniffer Subnet	500	7/13	269	7/13	269	7/13	269
Ctrl	5,000	1/13	385	1/13	385	1/13	385
Subnetwork MGR	10,000	1/13	769	1/13	769	1/13	769
or 1/6 of	60,000						
Totals			$24,184		$12,239		$5,823

Typical Subnetwork	Service Level	Quantity	Cost
	Full	3	$72,552
	PCN	6	73,434
	Terminal	4	23,292
	Total/Subnetwork		$ 169,278

Table 5-11. Basewide Broadband Coaxial Cable Network Costs

Component	Unit Cost	Source Table	Quantity	Total
Feeder Subnetwork Electronics	$169,278	(5-10)	4	$677,112
Backbone Electronics	139,000	(5-9)	1	139,000
Coaxial Cable Plant	233,330	(4-14)	1	233,330
		Network Total		$1,049,442

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

This document has described approaches to developing a survivable data network for mission essential communication on a typical flying mission base. In this section some performance factors are introduced and discussed, relative advantages are developed, and cost factors are summarized.

6.1 PERFORMANCE FACTORS

The network was segmented into four subnetworks to provide a high degree of survivability. An increased maximum data throughput benefit of having four hubs accrues to the centralized packet controller network but not to the contention broadband bus network. If the subnetworks are formed from users having a high rate of internal traffic, then a significant portion of the subnetwork traffic never crosses the backbone to other CPCs. Thus, the composite of all network traffic exceeds the capacity of any one CPC.

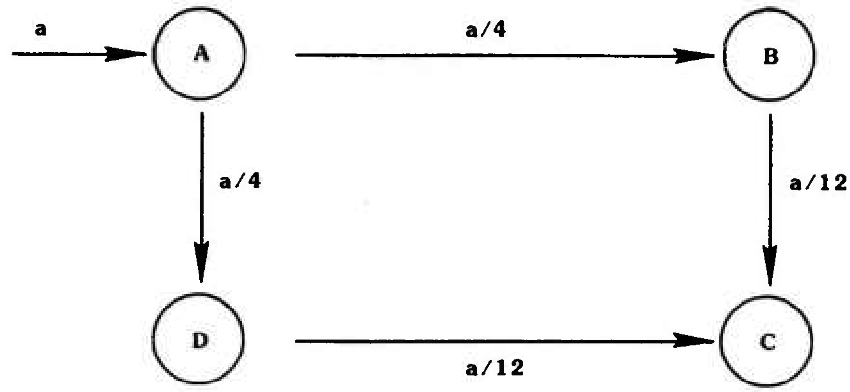
The increase in traffic capacity is demonstrated with the aid of figure 6-1. Several assumptions about traffic routing are made. The inbound traffic from subnetwork A is "a." Assume that half the traffic is for destinations within A and one-third of the remaining traffic is destined for each of subnetworks B, C, and D. Let half the traffic for C pass through B and the other half pass through D, as shown in figure 6-1a.

If all four subnetworks are generating inbound traffic with the same relative routing as A, then the total network traffic is as represented in figure 6-1 b. The traffic input to A (a typical packet controller) is

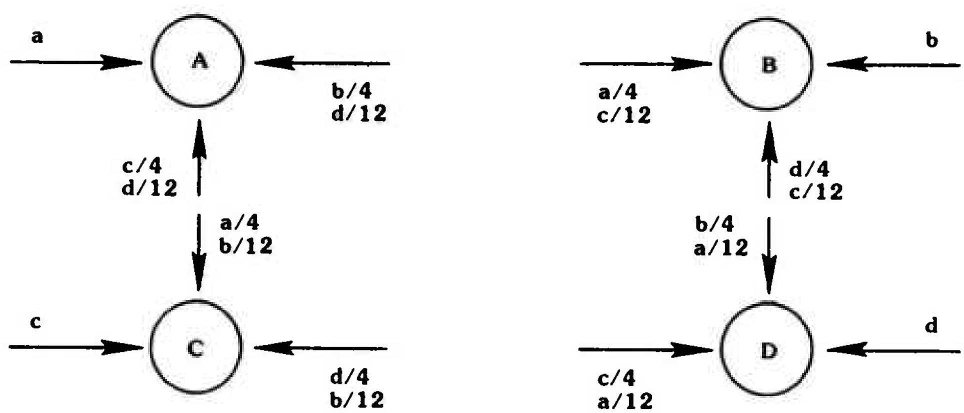
$$T = a + b/4 + c/4 + d/6 .$$

Assume that inbound traffic from each subnetwork is about equal to that from every other subnetwork ($a = b = c = d$). Then the traffic load on each CPC is

$$T = (5/3)a .$$



a) Distribution of subnetwork A's traffic



b) Distribution of all network traffic

Figure 6-1. Network Traffic Distribution

If the total traffic through each of the four CPCs is limited to its capacity S, then S = T max. Thus, the maximum input data rate from each subnetwork feeder is

$$a = (3/5)\ S\ .$$

Total network traffic with four subnetwork CPCs is

$$4a = 2.4\ S\ .$$

The ISN CPC has a data rate of 8.64 Mb/s. Therefore, the entire network, as described herein, has a total data transfer capability of greater than 20.7 Mb/s. Because contention is resolved without collisions, the full data transfer rate is available for useful transmission.

The broadband contention network does not offer a data rate enhancement as a result of the four headends. The broadcast nature of this type of network requires that only one headend be in operation at a time. The other three are in a standby mode at least as far as the basewide data channel is concerned. Traffic on a broadband contention network can never equal the burst data rate of the channel, which is 5 Mb/s in the case of the Ungermann-Bass BIUs. It is often assumed that throughput can approach 70% of the burst data rate for a relatively small network. Using this assumption, we find the network traffic on a single broadband channel to be 3.5 Mb/s or about 17% of that possible with a CPC. Multiple data channels may be accommodated (Ungermann-Bass equipment can utilize as many as five data channels) but will require interchannel bridging and additional sniffers on the inbound cable plant.

6.2 SPECIAL MEDIUM RELATED FACTORS

The fiber optic and coaxial cable media each provide a network with unique benefits. The benefits inherent in a fiber optic cable network are:

a. Every link on base is repeaterless. This includes the feeder network and backbone. In addition to enhancing reliability, the repeaterless nature of the fiber optic cable plant improves survivability, especially to sabotage. The entire plant is buried without the need for surface pedestals containing amplifiers. These surface pedestals that house electronics are obvious targets for saboteurs.

b. The unperturbed fiber optic waveguide does not radiate energy that can be intercepted, nor does it accept energy from local electrical disturbances including lightning.

c. The fiber optic medium is dielectric. Therefore, large destructive voltages cannot be induced across the medium by the effects of nuclear EMP.

d. The multimode fiber optic medium is a dual window fiber. The performance described herein has been achieved using low cost optical transmitters and receivers operating at 0.850 µm. By the time higher data rates are required, the cost of optical transmitters and receivers operating at 1.300 µm will have decreased to the price range of present 0.850-µm components. Use of 1.300-µm transmission increases the achievable data rate by a factor of 10. The presently unused single-mode fiber can extend the bandwidth by factors of 100 to 1000 depending on the optical source. Even if all 58 broadband coaxial channels were dedicated to digital transmission, the composite rate could be only 290 Mb/s.

The coaxial cable plant has a number of inherent advantages:

a. Subnetworks are easily formed by assigning a video channel to a group of users. If only users in that subset communicate on a channel, they can select BIUs to most fully meet their own requirements without concern for others on the broadband network.

b. The coaxial cable medium is ideal for transmission of wideband video channels. An analog signal may modulate an RF carrier corresponding to an available cable channel. Receivers tuned to that frequency anywhere on base can receive the analog signal.

c. As an extension of item "b" above, coaxial cable is an easy and inexpensive means for distributing television video. The equivalent uncompressed digital video signal requires 96 Mb/s of bandwidth.

6.3 SPECIAL ARCHITECTURE RELATED FACTORS

The network architecture affects how data packets are routed. Traditionally, broadband coaxial cable networks have used a linear bus or tree topology because of the large power margins offered when signaling on this medium. As a result of the lack of isolation of BIUs on the network, a broadcast form of transmission is employed. A packet that reaches the headend is broadcast to every BIU attached to the cable plant. That signal is also available at every multiport tap. This situation makes it easy for an intruder to connect to any multiport tap on the base and monitor and record any desired information regarding base operations. As in many military situations, individual transmissions may be unclassified, but the composite of many transmissions may compromise base security in a time of crisis.

The fiber optic medium does not lend itself well to power splitting. As a result, a meshed star topology is preferred. Separate optical fiber pairs originating in each building terminate at a specific port in the subnetwork hub electronics. Packets travel inbound over one fiber and travel outbound from the hub over only one fiber to the intended receiver. This is due to the switching action of the CPC. An intruder's tap within a building provides only data packets destined for that building. To access all subnetwork traffic, it will be necessary to monitor the short bus within the CPC itself. The total base traffic cannot be tapped at any one location. Thus, the fiber optic network offers an inherent security/privacy advantage because of data packet isolation.

6.4 FUTURE APPLICATIONS FACTORS

Once a major upgrade to the data network of a flying mission base is undertaken, the newly installed network should serve user needs for 30 years or more. Trying to predict user requirements and technology for 30 years would have been like trying to predict the present state of electronic sophistication and the proliferation of microcomputers in 1955, a few years after the invention of the junction transistor. The best that can be done is to project present trends and try to understand the implications. One dominant trend emerges--an ever greater need for high speed digital transmission.

In the area of office automation, two trends are at work that increase the need for high speed communications. Terminal-to-host traffic, as it exists today, is likely to be short lived. This kind of short packet bursty traffic is required when using dumb terminals. This kind of traffic has been adequately served by networks relying on CSMA access. With the replacement of terminals by microcomputers, the short packet interactive traffic will no longer be typical. Most of the form filling, word processing, spreadsheet, and design work will be done locally at a microcomputer. The microcomputer will require rapid downloading of applications software from a centralized software repository and the transfer of completed tasks to a central file, printer, or other microcomputers.

The second trend in office automation is the increasing reliance on bit mapped graphics for preparing figures and charts. Today, the Apple Macintosh microcomputer provides a screen resolution of 72 pixels per inch. If a one-page figure is to be transferred for printing on 8.5- by 11-inch paper with 1/2-inch borders, 388,800 pixels are required. Near term trends are toward very much higher resolution, and in the more distant future color will be added. Transfer of such files among a community of users will require data rates that can only be supported over a fiber optic plant.

At present, many networks are being implemented with broadband coaxial cable because of the need for video transmission. Today's television cameras contain modulators that directly generate the vestigial sideband signal for use within one of the 6-MHz coaxial cable channels. The receivers need only be switched to the appropriate channel to demodulate the signal.

Digital video encoders and decoders cost several thousand dollars today. With advances in VLSI, prices will probably drop sufficiently to allow codecs to be directly incorporated into the television camera and receiver. There are several incentives for this to occur. Picture quality becomes virtually independent of the transmission medium. With some added degree of compression, the encryption of teleconferencing video will become possible. Bandwidth reduction and encryption will allow teleconferencing to be used not only on a base but between bases over the Defense Data Network. Once again the fiber optic medium that is ideally suited to high speed digital transmission is the more appropriate medium for this type of service.

Other wideband signals, such as radar video or imagery, are best digitized upon reception for local processing or for digital transmission to a remote processor. In either case, it is most desirable to avoid the change in signal amplitude and phase and the addition of noise and harmonics that can be experienced if signals are transmitted in an analog form over a broadband coaxial cable plant.

6.5 RELATIVE COST FACTORS

Two cable plants were designed for a model flying mission base. Modern communication devices were used to form a data network in each case. The data networks offered a high degree of survivability by virtue of the segmentation of traffic into 4 subnetworks that serve 52 buildings having mission essential data traffic.

This report has shown that cost is not a factor in deciding between the two kinds of networks. The slight cost advantage of the fiber optic cable network could be lost or increased with different assumptions in our model.

The principal conclusion to be drawn from this comparative analysis is that fiber optics are not to be relegated to future network designs, but must be given serious consideration today. The selection of a medium must be based on factors other than cost. These include reliability; survivability; immunity to EMI, EMP, and RFI; and the suitability of the medium to handle future applications. Clearly the future will see a trend toward greater reliance on fiber optic LANs.

LIST OF REFERENCES

1. Carlisle, A.W., "Small-size High-performance Lightguide Connector for LANs," Paper TUQ18, OFC/OFS '85, February 1985 (AT&T Bell Laboratories, Norcross, GA).

2. Corguide Product Information dBF Optical Waveguide Fiber, Product 1519, Corning Glass Works, Corning, NY, September 1985.

3. Personick, S.D., "Receiver Design for Digital Fiber Optic Communication Systems, I.," BSTJ, Vol. 52, No. 6, July-August 1973.

4. Gloge, D., "Effect of Chromatic Dispersion on Pulses of Arbitrary Coherence," Electronics Letters, Vol. 15, pp. 686-687, 1979.

5. Fraser, A.G., "Toward a Univesal Data Transport System," IEEE Journal on Selected Areas in Communications, Vol. SAC-1, November 1983.

APPENDIX A

STARLAN (DRAFT PROPOSAL FOR ADDITION TO IEEE STD. 802.3)

StarLAN is a low cost 1-Mb/s CSMA/CD network that uses twisted copper pair as the transmission medium. Each station is linked to a hub by two twisted pairs. One pair connects to the inbound signal portion of the hub, and the other pair connects to the outbound (or broadcast) signal portions of the hub.

When hubs are cascaded as shown in figure A-1, a hierarchical star topology results. The network has the following characteristics:

a. 1-Mb/s data rate

b. Twisted pair wiring

c. Point-to-point interconnection of stations to hubs, with one twisted pair serving as the transmit channel, the other as the receive channel

d. Data pairs can coexist in the same telephone cable bundles as voice pairs.

e. When a hub receives signals from a station or lower-level hub, it propagates them to a higher-level hub if one exists; otherwise, the hub broadcasts the signals back down to the lower-level stations and hubs.

f. When a hub concurrently receives signals from two or more stations or lower-level hubs, or any combination, it generates a unique collision presence signal, and propagates or broadcasts it as in "e" above.

g. Station-to-hub and hub-to-hub interfaces are transformer isolated at both ends.

h. Up to five hub levels are allowed.

i. Maximum station-to-hub and hub-to-hub distance is approximately 250 meters for unshielded twisted pairs.

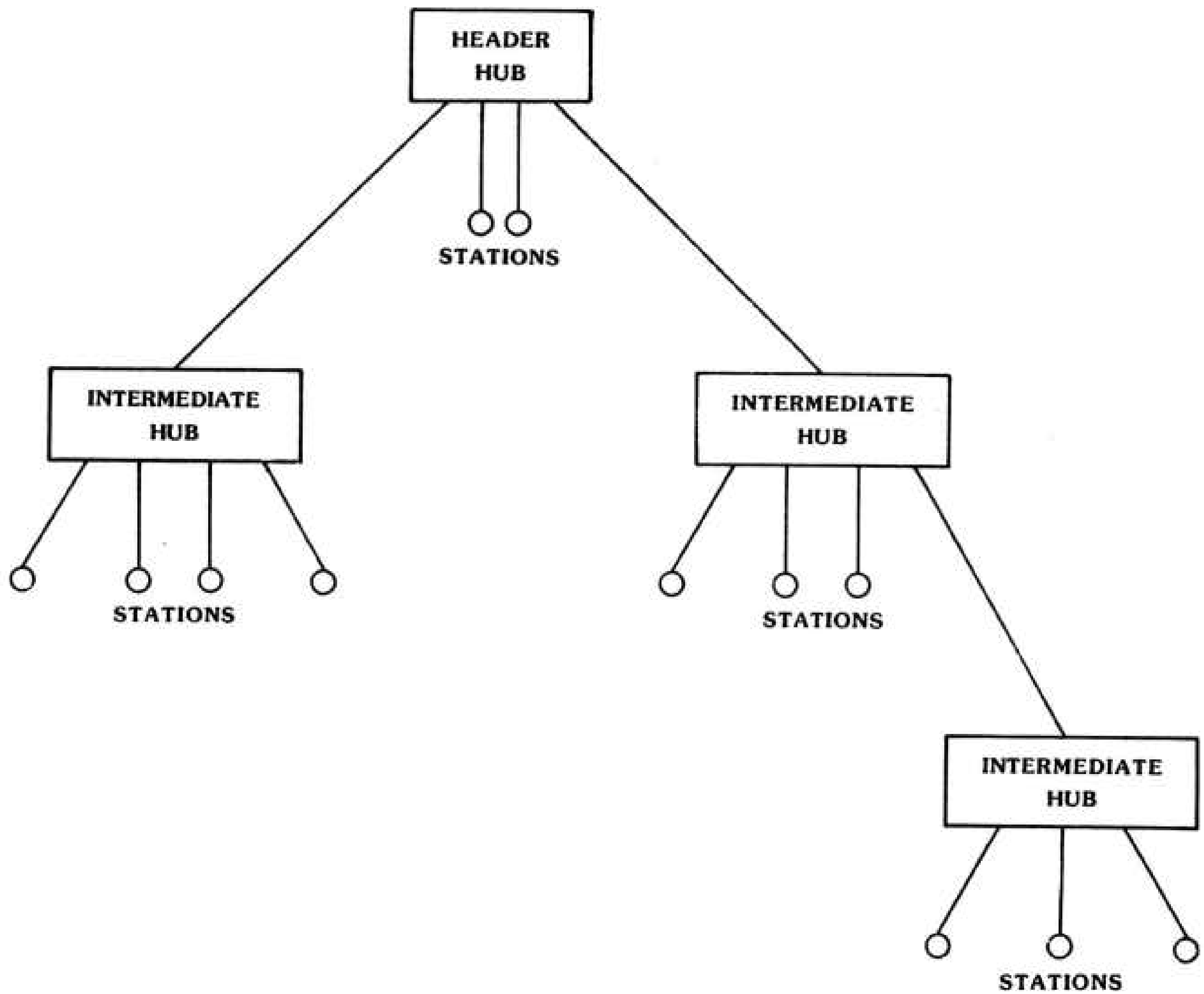


Figure A-1. StarLAN Network With Three Levels of Hubs

The hub is the point of concentration and performs two major functions: signal regeneration/retiming and collision detection. When one input to the hub is active, the hub repeats the signal and broadcasts it to the next higher-level hub. If two or more inputs to the hub become active at the same time, the hub generates a unique collision presence (CP) signal for broadcast. The hub sends CPs until all inputs become idle. The CP is detected by stations as Manchester code violations. The highest hub level, the header hub, broadcasts the inbound signal through intervening hubs to all attached stations. In the intermediate hubs, there is no electrical connection between the inbound and outbound portions of the hub.

The hub can detect unusually long transmissions to prevent jamming of the network by a runaway station (jabber control). If any input exceeds a duration threshold, CP is transmitted until all inputs become idle. Inputs not responding to CP are disabled by the hub.

The stations are required to communicate 1-Mb/s Manchester encoded signals and detect and suppress transmission in response to the CP signal. The packet consists of a preamble, a start-of-frame delimiter, data (including address), and an end-of-frame delimiter. The minimum packet length of 512 bits that has been specified is greater than what is needed to permit the collision detection algorithm to function for the maximum five-hub network. This packet length will allow successful collision detection on a network extending over tens of kilometers. However, the maximum distance limitation imposed by the proposed standard is 250-m between hubs or hubs and stations.

The 250-m distance limit is a result of shortcomings of signaling on unshielded 24-gauge twisted pair wire. The network must operate with termination impedances ranging from 68.5 ohm to 130 ohm (at 1 MHz). Signal attenuation and distortion lead to increased BER and accumulation of timing jitter with length. The waveform and amplitude are also constrained by consideration of near-end crosstalk. If distances greater than 250 m must be traversed, fiber optics provides an ideal transmission medium. Fiber optic extenders are not presently part of the StarLAN draft proposal.

The descriptions provided herein have been abstracted from the StarLAN draft B proposal (July 1985). A third draft (draft C) is planned for October 1985. Following revisions, it will be submitted to the IEEE 802.3 Working Group for inclusion in a future version of the 802.3 CSMA/CD Standard.

At present, ATTIS has developed station interfaces for asynchronous terminals via RS-232 (network interface unit, NIU) and for microcomputers and minicomputers at 1 Mb/s (network access unit, NAU).

The hub that is presently available does not regenerate/retime signals and is therefore suitable only on networks that do not extend over 250 m (within a building). As the standard is developed, the regenerator/retime function will be added to the hub (network extension unit).

APPENDIX B

ISN PACKET CONTROLLER

The ISN packet controller consists of two or four shelves. The first shelf, the data control unit (DCU), contains the modules that perform call processing, switching, administration, and maintenance. Individual modules in the DCU are listed in table B-1. The other shelf or shelves house the information interface carrier (IIC) that contains modules providing an interface between user devices, or the remote concentrator and packet controller. A list of currently available interface modules is provided in table B-2.

Table B-1. Data Control Unit (DCU)

Components	Characteristics	Functions
Control Processor	16-bit microprocessor design	Sets up and takes down calls after receiving "off-hook" signal and dialing information from a network device; establishes route to be taken by all data from that sender, until the sending or receiving device transmits "disconnect" signal. Automatically initiates a periodic status poll of modules in the information interface carriers (IICs) and concentrators and sends warnings of module failure to system control console processes and maintenance procedures.
Memory Module (RAM)	Provides total of 2 megabytes random access memory	Contains software for call processing and network management. Stores information on the arrangement of devices attached to the network, including tables of possible data routes, which are consulted by control processor in the course of call setup.
High Capacity Mini-Recorder (HCM-R)	Provides 23.5 megabytes of storage	Provides nonvolatile memory backup to protect against power outages and system downtime. Loads network control software into memory modules. Holds system configuration data for automatic restart after long-term power outage.
High Capacity Tape Interface (HCTI) Module		Formats information from the control processor for transfer to the HCM-R and vice versa.
Control Processor Interface Module (CPIM)		Provides the interface for messages passing from the control processor to the control interface module (CIM) and vice versa.
Control Interface Module (CIM)		Takes data forwarded by the CPIM from the control processor for transfer to the HCM-R and vice versa.
Maintenance module (MAINT)	Linked directly to system control console and printer	Passes signals between the system control console and the control processor in the packet controller so that messages regarding network administration and maintenance bypass the switch.

Table B-1. (continued)

Components	Characteristics	Functions
Channel Address Translator (CAT)	Hardware based packet switch	Stores in its memory a record of virtual circuits established by the control processor. Replaces source address of an incoming packet with its destination address according to the virtual circuit record, until the control processor takes down the call.
Clock Module (CLK)		Generates all system timing signals. Synchronizes packets passing through CAT with a series of electrical pulses. With the aid of repeater modules, transfers same transmission timing onto buses running behind device interface modules in the IICs.

Table B-2. Information Interface Carrier (ITTC)

Components	Characteristics	Functions
Repeater Module	One located on each IIC shelf.	Synchronize bus transmissions throughout the packet controller by repeating on each IIC shelf the timing signals generated by clock module in the DCU.
Asynchronous Interface Modules (AIM4 and AIM8)	One ICC carries up to 13 AIMs; one concentrator carries up to 5 AIMs. An AIM4 has four ports with nine EIA RS-232C leads each, providing hardware and software flow control; an AIM8 has eight ports with six EIA RS-232C leads each and supports optional software (XON/XOFF) flow control. Each AIM contains two 8-bit microprocessors, and each port has a maximum data rate of 19.2 kb/s full duplex. AIMs contain on-board nonvolatile memory for terminal configuration data.	Assemble data from transmitting asynchronous devices (terminals or hosts) into packets, implement protocols, and hold packets in buffers while awaiting opportunity to forward them to switch. Collect packets from switch, store them in buffers, dismantle the packet string, and send data out to final destinations. Permit alterations by system manager or end user of certain operating parameters for each port baud rate, autobaud rate detection capability, number of stop bits, parity standard, flow control method, automatic answering capability.
Fiber Interface Modules (FIMs)	Used in the packet controller or in slot 5 of the concentrator; each measures half the width of an AIM. As many as 16 FIMs occupy an IIC. Each provides one high-speed port, supporting multiple simultaneous virtual circuits.	Act as transmitters and receivers of data traveling over optical fiber between the packet controller and a concentrator, between a packet controller or concentrator and a DEC UNIX System V host computer equipped with a DUB/HI multiplexer, or between two interconnected packet controllers. Code and decode data in Manchester format for data transmission at 8.64 Mb/s on optical fiber.
Concentrator	A piece of equipment 6 inches high by 17.5 inches wide by 17 inches deep. Contains a control module called a concentrator common module (CCOM) and a power supply, plus one to five AIMs. Linked by optical fiber cable to FIM in packet controller. Can accommodate an FIM in slot 5 to serve a multiplexed host.	Via 5 AIM8s, connects up to 40 user devices to packet controller by multiplexing their data onto a single optical fiber pair. Concentrator common module (CCOM), containing fiber-optic transmitter and receiver, coordinates data sent to and from the devices the concentrator serves. The CCOM incorporates many of the functions performed by modules in the packet controller's DCU. It contains a clock that keeps the concentrator synchronized with the packet controller and a fixed translation switch that routes packets from the packet controller to the concentrator's various interface modules. AIMs in concentrator perform the same functions they do in the packet controller.
DEC UNIBUS Host Interface (DUB/HI)	A module inserted in a DEC UNIX host computer.	Provides interface between KMC-11 front-end processor of a DEC computer and an optical fiber link to an FIM in the packet controller (or a concentrator). Permits high-speed, multiplexed communication to a DEC UNIX host.
Protocol Converters	Each contains seven asynchronous ports and one synchronous port.	Enable asynchronous terminals, printers, and personal computers to emulate 3270-type terminals for access to IBM hosts. Two models are available: one supports BSC, one SNA/SDLC.

GLOSSARY

AB	air base
ADP	automatic data processing
ADPS	automatic data processing system
A&F	Accounts and Finance
AFB	Air Force base
AFCC	Air Force Communications Command
AGE	aerospace ground equipment
AIM	asynchronous interface module
AMS	avionics maintenance squadron
BER	bit error rate
BIU	bus interface unit
b/s	bits per second
BW	bandwidth
BX	base exchange
CAT	channel address translator
CB	contention bus
CCOM	concentrator common module
CEMS	comprehensive engineering management system
CIM	control interface module
CLK	clock
CP	collision presence
CPC	centralized packet controller
CPIM	control processor interface module
CSC	central security control
CSMA/CD	carrier sense multiple access/collision detection
dB	decibel
dBm	decibels referred to 1 milliwatt
dBmV	decibels referred to 1 millivolt
DCU	data control unit
DP	digital PBX
DPI	data processing installation
DTE	data terminal equipment
EMI	electromagntic interference
EMP	electromagnetic pulse
FAB	fabrication
FIM	fiber interface module
FMS	field maintenance squadron
FO	fiber optic

FTD	field training detachment
FWHM	full width half maximum
FY	fiscal year
h	hour(s)
HCM-R	high capacity mini-recorder
HCTI	high capacity tape module
IIC	information interface carrier
ILD	injection laser diode
I/O	input/output
ISN	Information Systems Network
ISS	Information Systems Squadron
IU	interface unit
kb/s	kilobits per second
km	kilometer
LAN	local area network
LED	light emitting diode
m	meters
MA	office symbol of Deputy for Maintenance
MAC	Military Airlift Command
Mb/s	megabits per second
MET	manpower engineering team
MMS	munitions maintenance squad
MWR	morale, welfare, and recreation
NAU	network access unit
NCO	noncommissioned officers
NEU	network extender unit
NIU	network interface unit
nm	nanometer
NMC	network management console
ns	nanosecond
NTSC	National Television Standard Committee
OD	outer diameter
OMS	Organizational Maintenance Squadron
OSI	Office of Special Investigations
Pack and C	packing and crating
PBX	private branch exchange
PC	personal computer
PCN	personal computer network
PDO	publications distribution office
PIN	positive intrinsic negative
PMEL	precision measurement equipment laboratory

RACC	Repairable Assets Control Center
RAM	random access memory
RF	radio frequency
RFI	radio frequency interference
rms	root mean square
ROM	read only memory
SAC	Strategic Air Command
SDM	short distance modem
SM	single mode
SP	Security Police
SPOL	Security Police Squadron
SQ	squadron
SSTR	star shaped token ring
TA	transit alert
TAC	Tactical Air Command
TDM	time division multiplexing
TPB	token passing bus
WDM	wavelength division multiplexing
μm	micrometer